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FINAL REPORT

DETERIORATION OF FUELS  
AND FUEL-USING EQUIPMENT

SRI SUBCONTRACT NO. B-70922 (4Y49A-27)-US  
OCD WORK UNIT 1413A  
August 1967

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BATTELLE MEMORIAL INSTITUTE  
Columbus Laboratories  
505 King Avenue  
Columbus, Ohio 43201

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# FINAL REPORT

## DETERIORATION OF FUELS AND FUEL-USING EQUIPMENT

Prepared by  
D. A. Trayser, G. M. Hein, and W. C. Ellis

Prepared for:  
OFFICE OF CIVIL DEFENSE  
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OFFICE OF THE SECRETARY OF THE ARMY  
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## TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION . . . . .	1
SUMMARY . . . . .	1
CONCLUSIONS AND RECOMMENDATIONS . . . . .	3
REVIEW OF AUXILIARY POWER SYSTEM REQUIREMENTS . . . . .	4
SHELTER POWER SYSTEM PERFORMANCE IDEALS . . . . .	7
System Dependability . . . . .	7
Characteristics of the Ideal Fuel-Supply System . . . . .	8
Fuel Quality . . . . .	8
Fuel-System Surfaces . . . . .	9
Fuel-System Auxiliaries . . . . .	9
Fuel Tank Location . . . . .	9
Characteristics of the Ideal Prime Mover . . . . .	9
Dependability . . . . .	10
Deterioration Resistance . . . . .	10
Simplicity . . . . .	10
PRESERVATION AND STANDBY MAINTENANCE . . . . .	11
Fuel Storage and Deterioration Characteristics . . . . .	11
Fuels for Spark-Ignition Engines . . . . .	11
Fuels for Compression-Ignition Engines . . . . .	16
Fuels for Gas Turbines . . . . .	20
Fuel-Storage Facilities . . . . .	20
Summary of Fuel Storability . . . . .	25
Storage of Prime Movers . . . . .	25
Basic Requirements of Standby Storage . . . . .	25
Specific Storage Characteristics of Prime Mover Systems . . . . .	29
Current Standby Maintenance Practice . . . . .	30
Pertinent Storage Experience . . . . .	33
STANDBY MAINTENANCE ROUTINES FOR SHELTER POWER SYSTEMS . . . . .	36
Fuel System Maintenance . . . . .	36
Selection of Fuels . . . . .	36
Selection of Storage Facilities . . . . .	37
Fuel Storage Routines . . . . .	39
Prime Mover Maintenance . . . . .	43
Selection of Equipment and Facilities . . . . .	43
Active Standby Maintenance . . . . .	46
Passive Standby Maintenance . . . . .	48

Page

RESULTS OF COST ESTIMATIONS . . . . .	48
FUTURE RESEARCH NEEDS . . . . .	59
In-Storage Evaluation of Selected Fuels . . . . .	59
Experimental Study of Prime Mover Passive Storage . . . . .	60
Fuel Deterioration Tolerance of Engines . . . . .	61
LIST OF REFERENCES . . . . .	63

APPENDIX A

COMPLETE TABULATION OF SYSTEM COST ESTIMATION RESULTS . . . . .	A-1
---	-----

APPENDIX B

PRESERVATIVES-SPECIFICATIONS AND DESCRIPTIONS . . . . .	B-2
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## LIST OF ILLUSTRATIONS

	<u>Page</u>
Figure 1. Underground Vented Fuel-Storage System . . . . .	22
Figure 2. Underground Sealed Fuel-Storage System With Positive Nitrogen Pressure . . . . .	24
Figure 3. Underground LPG Fuel-Storage System . . . . .	24
Figure 4. Estimated Storage Life of Representative Fuels . . . . .	26
Figure 5. Effect of Humidity on the Corrosion of Steel . . . . .	28
Figure 6. Estimated Fuel Tank Purchase and Installation Costs . . . . .	38
Figure 7. Effect of Exercising Routine on Total System Cost . . . . .	54
Figure 8. Effect of Engine Type on Total System Cost . . . . .	55
Figure 9. Effect of Fuel Storage Facility on Total System Cost . . . . .	56
Figure 10. Effect of Fuel Type on Total System Cost . . . . .	57
Figure 11. Comparison of Shelter Power System Cost Breakdowns for Principal Engine Types . . . . .	58

## LIST OF TABLES

Table 1. Fuel Requirements for Shelter Power Systems . . . . .	37
Table 2. Suggested Procedures for Fuel Storage Routines Using a Sealed Underground Tank . . . . .	40
Table 3. Suggested Procedures for Fuel Storage Routines Using a Vented Underground Tank . . . . .	41
Table 4. Suggested Procedures for Fuel Storage Routines Using a Sealed Underground Tank with Nitrogen Blanketing . . . . .	42
Table 5. Estimated Shelter Power System Purchase and Installation Costs . . . . .	45
Table 6. Suggested Procedures for Active Maintenance Program with Frequent Exercising . . . . .	47
Table 7. Suggested Procedures for Active Maintenance Program with Infrequent Exercising . . . . .	49
Table 8. Suggested Procedures for Passive Maintenance Program . . . . .	50
Table 9. Total Estimated Costs for Acquisition, Installation, and Standby Maintenance of Selected Fuel Systems and Engine Exercising Routines . . . . .	52

SUMMARY OF RESEARCH REPORT

DETERIORATION OF FUELS AND FUEL-USING EQUIPMENT

August, 1967

This is a summary of a report which has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views of the Office of Civil Defense.

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Summary Prepared by

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## SUMMARY OF RESEARCH REPORT

on

## DETERIORATION OF FUELS AND FUEL-USING EQUIPMENT

### SCOPE

In a general study of auxiliary power system requirements for community protective shelters, completed in June, 1964, it was noted that long-term preservation and storage of fuels had received little attention in the literature, and that the meager information that was available could not be readily applied to the shelter circumstances. It was also noted that existing practices for long-term preservation and storage of equipment were complex and expensive, and that time requirements for reactivation were excessive. In both cases, however, it was felt that improved methods for standby storage of fuels and equipment could be developed without too great an extension of current knowledge and practices.

This report covers the results of additional studies which were aimed at establishing more precisely the deterioration characteristics of fuels and equipment in storage and devising standby storage techniques which would more nearly satisfy the requirements of the community shelter program.

### OBJECTIVES

The objectives of the study were:

1. To determine the current state-of-knowledge on the deterioration of fuels and fuel-using equipment in storage.
2. To study the current methods and practices for the preservation of fuels and equipment in storage.
3. To devise improved methods for standby maintenance of shelter auxiliary power systems.

### APPROACH

The study included: literature and field investigations; consideration of materials, equipment, and techniques utilized for long-term storage of fuels and prime movers; and conception and cost analysis of specific standby maintenance

procedures for shelter power systems. In the literature and field investigations, pertinent literature from the World War II period to the present was studied, and visits and telephone and letter contacts were made with individuals and organizations active in related fields. All long-term-storage materials, equipment, and techniques that had been or are being used were evaluated for their relevance to the needs of shelter auxiliary power systems.

On the basis of the results of the investigations and evaluations of the current state of knowledge, a number of specific standby maintenance routines were devised for shelter power systems, and estimates were made of the costs of the required equipment, materials, and labor. These cost estimates were compared on the basis of 5-, 10-, and 15-year standby periods. Conclusions were drawn from these cost comparisons regarding the most appropriate approaches to shelter power system standby maintenance. Also, several technological areas were identified where in specific research programs might be expected to lead to useful advances in the state of knowledge.

### RESULTS AND CONCLUSIONS

Gum and sediment are the principal forms of deterioration that occur in a fuel in storage. Commercial gasoline and diesel fuels have limited but encouraging storability. For instance, certain commercial gasolines may store without appreciable deterioration for from 2 to 5 years depending on the storage conditions, and some commercial diesel fuels may store for periods up to 10 years or more without appreciable deterioration. There is also strong evidence that gasoline and diesel fuels specially refined or blended for long storage life could be obtainable at a nominal premium price - say 10 to 20 percent above commercial prices. These special fuels might have storage life in excess of 15 years. Commercial LTC and alcohol fuels could be expected to have relatively unlimited storage life.

Since the deterioration of fuels is principally caused by the presence of oxygen and moisture, fuel storage life can generally be increased by one or more of the following techniques: burying the fuel tank underground to reduce the temperature variations which cause air to enter the tank and fuel vapors to be lost, sealing the tank vent with a valve system which would further reduce the entrance of air and loss of vapors, and providing a blanket of nitrogen gas over the exposed surface of the fuel to completely exclude oxygen and moisture.

Corrosion and surface fouling are the greatest enemies of equipment in storage. A complex piece of equipment, such as an internal combustion engine, left exposed to the atmosphere without any protection for a year or more would probably become so corroded and fouled that it could not even be cranked over, much less started. Fuel left in a fuel system for the same length of time would evaporate or become gummy and leave deposits at critical locations which would probably render the system inoperable. Protecting the exposed and critical surfaces with preservatives would extend the period of time during which a piece of equipment would remain operable in storage. The most important thing that can be done, however, to protect equipment in storage is to maintain the relative humidity in the storage environment at or below 50 percent.



The conventional approach to maintaining an emergency standby engine generator set has been to exercise and inspect the system frequently. General practice seems to be to do this on a weekly basis. This procedure is appropriate when it is considered that most installations are under the care of building engineers or superintendents with other duties to perform also, and that the engine is expected to start and deliver power almost immediately when there is a commercial power failure. Utilizing this same approach for a community shelter system may result in an excessive and unnecessary cost burden. On the other hand it has not been fully demonstrated yet that completely inactive storage in a dehumidified warehouse can provide the desired reliability with an acceptably short reactivation time.

A number of standby maintenance routines for community shelter power systems were devised using the best information available from the literature and from field experience. The acquisition, installation and maintenance costs for these systems were estimated and compared with each other. The conclusions which resulted are as follows:

1. Utilizing an industrial duty gasoline engine results in the lowest overall cost.
2. A standby maintenance routine for the engine including controlled humidity in the engine room, a rust inhibitor in the engine cooling system, a preservative oil in the engine lubrication system, and exercising and inspecting the engine once every six weeks, would result in maximum cost effectiveness.
3. Using a sealed fuel tank or a nitrogen blanket system offers only a small cost advantage over the underground vented tank.
4. The use of fuels specially blended for long storage life offers some cost advantage over commercial fuels especially for long-term storage periods.
5. The overall cost of the auxiliary power system including maintenance is relatively insensitive to the cost of the fuel and fuel system.

The results of this study seem to indicate that commercially available fuels and equipment and nearly conventional standby maintenance practices would be adequate for a community shelter system. However, it is recommended that OCD seek additional knowledge and experience in the following areas: long-term storage effects on commercial and special fuels and lubricants, inactive storage of engine generator sets in a reasonable state of readiness, and the fuel deterioration tolerance of gasoline and diesel engines. Specific experimental research programs in each of these areas should provide a significantly increased level of confidence in the best methods of standby maintenance of shelter power systems.

DETERIORATION OF FUELS AND FUEL-USING  
EQUIPMENT SUBCONTRACT NO. B-70922  
(4949A-27)-US SUBTASK 1413A

by

D. A. Trayser, G. M. Hein, and W. C. Ellis

INTRODUCTION

A study of auxiliary power system requirements is described in a Battelle-Columbus report dated July 15, 1964, to the Office of Civil Defense, "Minimum Requirements for Auxiliary Power Systems for Community Shelters," by D. A. Trayser, L. J. Flanigan, and S. G. Talbert, prepared under Contract No. OCD-OS-62-190, Subtask 1411C. The report includes sections on fuel storage and on stand-by maintenance which cover current knowledge and experience in these areas of technology. During the study it was noted that long-term preservation and storage of fuels has received little attention in the literature and that the information that is available is inconclusive for the community shelter application. It was also noted that the current practices for long-term preservation and storage of equipment are complex and costly, and that time requirements for reactivation are excessive. In both cases, however, it was determined that improved methods for standby storage of fuels and equipment can be developed without too great an extension of the state of knowledge and change of current practices.

This present report covers additional studies conducted for the Stanford Research Institute under Subcontract No. B-70922 (4949A-27)-US to establish more precisely the deterioration characteristics of fuels and equipment and to devise, and estimate the cost of standby storage techniques which would more nearly satisfy the requirements of the community shelter program.

SUMMARY

The study described in this report covered two closely related areas of investigation: (1) the deterioration of fuels and equipment in storage and (2) the standby maintenance requirements of auxiliary power systems for community protective shelters. Determination of the state-of-knowledge and current practices in the first area of investigation led to the devising of specific plans of action in the second area.

The study included: literature and field investigations; consideration of materials, equipment, and techniques utilized for long-term storage of fuels and prime movers; and conception and cost analysis of specific standby maintenance procedures for shelter power systems. In the literature and field investigations, pertinent literature from the World War II period to the present was studied and visit and telephone and letter contacts were made with individuals and organizations active in pertinent fields. All long-term storage materials, equipment, and techniques that had been or are being used were evaluated for their relevance to the needs of shelter auxiliary power systems.

On the basis of the results of the investigations and evaluations of the current state of knowledge, a number of specific standby maintenance routines were devised for shelter power systems, and estimates were made of the costs of the required equipment, materials, and labor. These cost estimates were compared on the basis of 5-, 10- and 15-year standby periods. Conclusions were drawn from these cost comparisons regarding the most appropriate approaches to shelter power system standby maintenance. Also, several technological areas were identified wherein specific research programs might be expected to lead to significant advances in the state of knowledge.

The main body of this report consists of five major sections:

- o Shelter Power System Requirements
- o Shelter Power System Performance Ideals
- o Preservation and Standby Maintenance
- o Standby Maintenance Routines for Shelter Power Systems
- o Future Research Needs

The major components of a typical shelter power system would be: the prime mover, a power-transmission system, a cooling system, a starting system, and a fuel system. Appropriate alternatives for each of these components are described in the report. The installation of a shelter power system also requires special attention to equipment mounting, noise suppression, ventilation, and standby maintenance.

The ultimate requirement of a shelter power system is that it start and operate dependably in an emergency. In the ideal case, all steps necessary to assure this dependability would be taken. An ideal fuel would be one which would not deteriorate or cause deterioration in the system during a standby period of 10 years or more. An ideal prime mover also would not deteriorate during standby and would start immediately on demand and deliver full power for as long as necessary. Practical economics, however, dictate that compromises be made in the selection of fuel, prime mover, and maintenance procedures.

Formation of gum and sediment is the principal form of deterioration in a fuel in storage. Commercial gasoline and diesel fuels have limited but encouraging storability. Certain commercial gasolines may be stored without appreciable deterioration for 2 to 5 years, depending on the storage conditions. Some commercial diesel fuels may be stored for periods of 10 years or more without appreciable deterioration. There is strong evidence that gasoline and diesel fuels specially refined or blended for storage life greater than 10 years could be obtained at a nominal premium price, possibly 10 to 20 percent above commercial prices. Commercial LPG and alcohol fuel may have relatively unlimited storage life. However, specific and detailed information on fuel long-term storability is relatively sparse.

Corrosion and surface-fouling are the greatest forms of deterioration in equipment in storage. The conventional approach to maintaining a standby power system, i.e., frequent exercising and inspection, has been very successful in meeting the particular requirements for emergency standby power. However, various warehousing and mothballing programs have amply demonstrated that deterioration of equipment in storage can be significantly inhibited by careful preparation for storage and by maintaining a 40 to 50 percent relative humidity in the storage environment. Prime movers in a reasonable state of readiness have been kept in inactive storage to a limited extent with some success. However, not much detailed information is available.

A number of plans for standby-maintenance routines for community shelter power systems were devised during the study. These plans are based on the best information available from the literature and from field experience. The costs for acquisition, installation, and maintenance of these systems and for the standby maintenance routines are estimated and compared on the basis of 5-, 10-, and 15-year standby periods. From the results it appears that a gasoline engine power system utilizing commercial fuels and preservatives, maintained in a low-humidity environment, and exercised every 6 weeks, would provide maximum cost effectiveness considering the present state of knowledge.

It was noted during this study that information is particularly sparse in the areas of: long-term storage effects on commercial and special fuels and lubricants, inactive storage of engine-generator sets in a reasonable state of readiness, and the fuel-deterioration tolerance of gasoline and diesel engines. Recommended specific research programs to close each of these technological gaps are briefly described.

#### CONCLUSIONS AND RECOMMENDATIONS

The information developed during this research study leads to the following general conclusions:

1. Fuel systems capable of supplying good-quality fuel immediately on demand, at any instant during a time span of 15 years (or more), can be acquired and maintained at costs commensurate with the purpose.
2. Engine systems capable of starting and operating for a period of at least two weeks, after a storage period of 15 years or more, also can be acquired and maintained at costs commensurate with the purpose.

More specific conclusions regarding the types of equipment and the maintenance procedures most appropriate to community shelters are as follows:

1. An engine standby maintenance routine specifying exercising and inspection every 6 weeks, coupled with maintaining controlled low humidity in the engine room, would provide maximum cost effectiveness.
2. Reducing the exercising frequency to once every year would result in small cost reductions for the longer standby periods, but the present state-of-knowledge is inadequate to justify this option.
3. A gasoline engine and suitable fuel system would comprise the lowest-cost equipment acceptable for the application.
4. A sealed underground tank would be the best choice of facilities for fuel storage.
5. The potential cost reductions which may result from using a special-blend gasoline are not sufficient to justify the problems and complexities of obtaining the special fuel.

The information and experience which were evaluated in the course of this research program were for the most part not explicitly directed to the specific requirements of community shelters. For this reason, it is recommended that OCD seek additional knowledge and experience with respect to the following: long-term effects of storage on commercial and special fuels and lubricants, results of inactive storage of engine-generator sets in a reasonable state of readiness, and fuel-deterioration tolerance of gasoline and diesel engines. Specific experimental research programs in each of these areas should significantly increase the level of confidence in the possibility of selecting the best methods of standby maintenance of shelter power systems.

#### REVIEW OF AUXILIARY POWER SYSTEM REQUIREMENTS

A typical auxiliary power system for a community fallout or blast shelter would consist of the following major components: a prime mover, a power-transmission system, a cooling system, a starting system, and a fuel system. A number of alternatives are commercially available for each of these major components; however, the particular requirements of the shelter application narrow the selection to a certain extent. Unfortunately, there is no single combination of components that would appear to be clearly superior for all possible shelter applications, consequently, the shelter designer must seek an appropriate match between the available components and his particular shelter requirements, with reliability and low cost as paramount considerations.

The prime movers most suitable for shelter power are spark-ignition LPG and gasoline-fueled engines and compression-ignition diesel-fueled engines. These engines have been well proven through many years of both emergency-standby and continuous-duty service, are readily available in many sizes, are easy to install, and are relatively inexpensive. Gas turbines are fundamentally simpler prime movers and would probably be easier to maintain through long idle periods. However, they are not yet readily available, particularly in the lower power range, and they are expensive.

There are four principal means for converting the engine power into useful work: electric, hydraulic, pneumatic, and direct drive. From the standpoints of flexibility, first cost, operating efficiency, and maintenance, the electric generator is the most logical power-transmission system to use in a shelter. For powering large items of shelter equipment, a mechanical system would be more advantageous because of its simplicity and high efficiency. However, it would not be practical to supply mechanical-drive power to remotely located equipment, and a small electric generator would still be required to provide power for lights and communication equipment.

The principal cooling techniques for power-system installations of this type are: the use of well water or water from storage supplied directly in the engine, a water-to-water heat exchanger, a conventional air-cooled radiator, and an ebullient or vapor-phase cooling system. With an abundant supply of relatively clean water available to the shelter, the direct well or stored-water cooling system would be the simplest and least expensive. A water-to-water heat exchanger would be a second choice under those conditions. To conserve the supply water, a cooling tower or spray pond could be used in conjunction with the heat exchanger to dissipate heat from the external water system, but these components would be vulnerable to damage by heat and blast effects and would be more difficult to maintain in standby storage. The air-cooled radiator is used in the majority of conventional standby power systems, except where waste heat recovery is practiced. The radiator would be the only choice where supply water is not available. Ebullient cooling is basically simpler than radiator or heat-exchanger cooling and requires significantly less make-up water than direct water cooling or heat-exchanger cooling. However, engines must be specially designed for ebullient cooling to avoid pocketing in the cooling water passages, which might lead to hotspots, and to withstand the higher water pressures and temperatures.

All prime movers require some type of externally powered starting device. The starting systems most commonly used are: manual, pneumatic, hydraulic, and electric. Starting by means of hand-cranking is practical only for engines up to about 20 or 30 horsepower. If an engine becomes hard to start for any reason, manual cranking may be wholly inadequate. Pneumatic, hydraulic, and electric starting systems depend primarily on a source of stored energy. The pneumatic and hydraulic systems are relatively expensive and, therefore, somewhat less attractive than the electric system. However, the hydraulic starting system can be provided with a means for manual recharging and therefore should be considered competitive with the electric starting system in relation to standby reliability. Practically all conventional emergency standby power systems utilize electric starting because of its low first cost and general reliability.

The fuel system for a shelter power system will depend on the type of fuel required by the engine, the storage stability of that fuel, and the method of standby maintenance to be practiced. Spark-ignition engines may be equipped to use either gasoline in a commercial grade or specially blended, or LPG. Compression-ignition engines can generally use No. 1 or No. 2 diesel oil or kerosene. Gas turbines will run with any of these fuels plus jet aviation fuel. However, the heavier diesel fuels and leaded gasoline are detrimental to turbine life.

Fuel storage facilities range from very simple, aboveground vented tanks, to underground sealed tanks with nitrogen blanketing systems. The fuel system will also include a means for transferring the fuel to the engine, shut-off valves, and a "day tank" mounted on or near the engine and containing a small supply of fuel.

There are several important items that must receive close attention when the installation of an auxiliary power system is being planned. These are: mounting, noise, ventilation, and maintenance. A mounting technique should be selected to prevent vibration from developing within the mounted components and from being transmitted to or from other parts of the shelter. In addition, a good mounting system must provide accurate alignment between driving and driven components, and should minimize piping and wiring connection problems. Skid mounting, with engine, generator and controls on a common steel-rail framework, is the most commonly used approach and is usually the least expensive.

Some control over the noise generated by an auxiliary power system is necessary. In most cases, effective noise reduction can be obtained by the use of barriers between the engine room and occupied spaces, by proper inlet and exhaust muffling of the engine, by preventing vibration transmission from the engine, and by providing "sound traps" in air ducts between the engine room and occupied space.

The cooling system handles only about 40 percent of the total heat that must be rejected as waste heat from an engine. Another 40 percent goes out with the exhaust gases. The remaining 20 percent must be transferred to the air around the engine, by radiation and convection. Eventually this heat must be rejected outside the shelter by some means. Substantial amounts of heat will also be added to the engine room air by the generator. The simplest way to take care of this radiative and convective heat is by providing sufficient ventilating air to the engine room. In most shelter installations the minimum ventilating air rate required to supply oxygen for the shelter occupants would be sufficient to maintain a tolerable temperature in the engine room also, if exhaust was through the engine room. On the other hand, radiator cooling systems require several times more air than that required for removal of radiative and convective heat from the power system. Supplying this amount of air from the shelter occupied space would necessitate a significant increase in the ventilating rate. Consequently, it might be more practical to ventilate the engine room independently from the occupied space. The engine room ventilating air should not have to be as carefully filtered as air for the occupied space since fallout particles are not expected to interfere with the power system operation for the two-week occupancy period.

It should be anticipated that some servicing and maintenance of the power system will be required during a stand-by period of 10 years; hence, the installation should be planned to allow easy access to all sides of the engine and generator. Critical fuel lines, wires, etc., should not be exposed to accidental damage during servicing or otherwise. Equipment and components requiring periodic attention should be placed in convenient locations, preferably near the entrance. Ventilation inlet and exhaust systems should be protected from vandalism or other damage and should be protected against the entry of dirt or moisture during the standby period. In general, the more attention given during installation to simplifying servicing and preventing damage and deterioration, the less costly and complex will be the job of standby maintenance, and the more reliable the overall installation.

## SHELTER POWER SYSTEM PERFORMANCE IDEALS

### System Dependability

The selection of a power-generation system for an emergency shelter requires great concern about a unique set of dependability factors. There must be a very high probability for immediate trouble-free starting of the prime mover after a long period of complete idleness (possibly 10 years or more), coupled with continuous trouble-free performance thereafter - but only for a relatively short period (about two weeks). Also, the engine may not be required under the circumstances to operate according to standards which apply to normal usage.

Basic to engine-operation dependability, of course, are prompt fuel delivery to the engine and the suitability and quality of the fuel delivered. The promptness factor is the most crucial for the entire fuel-supply system. Certain flexibilities are permissible in the engine-design/fuel-composition relationship without detracting from the required high probability for trouble-free starting and adequate power-generation. But there can be no compromise about insuring that fuel will reach the engine's combustion chambers immediately on demand.

Therefore, decisions about type and initial quality of fuel and provisions for its long-term storage must focus primarily on those factors which can conceivably contribute to the hampering of fuel flow from the supply reservoir to the engine at literally any instant during a period of perhaps 10 years or more from the time the emergency-power system is installed.

It is thus apparent that the following two objectives are pivotal for fuel-procurement and storage planning:

- A. The fuel per se must not contain initially, or be prone to generate, amounts of sediment or resinous materials which, conceivably, could significantly restrict flow of fuel into the combustion chamber of the engine.
- B. The fuel-storage system must be so contrived that:
  1. It will provide ample protection for the fuel against those environmental influences which conceivably could significantly enhance its characteristic sediment - or resin-generation propensities
  2. It will not itself contribute significantly to sediment and/or resin formation in the fuel
  3. It is structurally secure against most conceivable potential sources of significant damage.



It is obvious that objectives A and B have mutually dependent aspects, and it is to be expected that these aspects will become particularly critical as economic matters are taken into account. For instance: the chemistry of a particular fuel can impose certain requirements on the construction of the storage system; on the other hand the features of a particular storage system can impose certain requirements with respect to the chemistry of the fuel. In either case, the economic aspects or practicality of the requirements can force consideration of various compromises or alternatives.

It is also obvious that engine characteristics must enter into the planning. These, for the most part, are automatically anticipated during considerations about fuel composition and quality. However, there must be special concern about conceivable harmful stagnation effects of fuel that might be allowed to age in the idle engine either by necessity or because an engine break-in and periodic-exercise routines are followed. This alone could impose severe requirements on the fuel with regard to both purity and composition.

Therefore, it is abundantly clear that plans for the fuel-supply system must center on fuel-quality considerations. And, since factual information available to date in this connection is only partially pertinent, the decisions about fuel quality must involve allowance for a considerable safety (or dependability) margin. The term "conceivable" which appears several times in the foregoing paragraphs underscores the fact that the decisions about fuel quality must entail guesses or extrapolations from the limited data now on hand.

For problems as complex as this, it is helpful to identify the parameters of an ideal solution. This can provide criteria by which to estimate the dangers, penalties, and implications of compromises which must inevitably be involved in the practical solution.

#### Characteristics of the Ideal Fuel-Supply System

If all of the conditions for an ideal fuel-supply system were to be met as suggested below, there would be essentially 100 percent probability that fuel would "reach the engine" immediately on demand at any time during a 10-year period, and possibly even during a 50- or 100-year period. It may prove too costly to achieve this ideal situation, duplicated thousands of times over. But in any case, compromises should be evaluated primarily against dependability rather than cost criteria. Four considerations are of most importance: fuel quality, fuel-system surfaces, fuel system auxiliaries, and fuel tank location.

#### Fuel Quality

The fuel as initially procured should be of such quality that, during the entire storage period envisioned (10 years or more) when given "suitable protection", it will never be found to contain more sediment, resins or gums than would be considered the maximum in commercial usage.

In essence, this is saying that present commercial specification limits for a particular type of fuel should comprise the aging maxima for a similar type of fuel procured for shelter power systems. Such a requirement automatically satisfies a large part of the "engine-dependability" requirement discussed earlier. That is, commercial specification limits for fuels tend to be both conservative and geared to engine-performance maxima considerably in excess of that required by shelter power systems.

#### Fuel-System Surfaces

All surfaces of the fuel system with which the fuel stays in contact during storage should be initially so clean that they contribute no sediment or gum to the fuel. Also, they should contain no materials (especially copper in any form) which will catalyze or otherwise promote chemical changes in the fuel.

#### Fuel-System Auxiliaries

Provisions should be made for fine filtration and dehydration of the fuel as it is charged to the tank, for immediate removal of essentially all dissolved and free air from the system, and for maintaining essentially anaerobic conditions in the system during the entire storage period.

#### Fuel-Tank Location

The entire fuel system, including the tank, should be contained inside the shelter and mounted together with the engine on a single supporting block. This would drastically reduce the probabilities for either catastrophic exterior corrosion of any part of the system or accidental breakage of fuel lines from the tank to the engine.

Further, a manifolded fine-filtration and water-separation facility should be provided between the fuel tank and the engine.

#### Characteristics of the Ideal Prime Mover

The ideal power system, that is, one that could be counted on to perform as required at any time during a 10-year period or more, may also prove to be too costly for the practical situation. However, here also it is well to

set forth the ideal requirements, so that alternative practical systems can be compared with each other with reference to the ultimate requirements. This will make possible evaluating compromises against both dependability and cost criteria.

### Dependability

The principal dependability requirements of a prime mover are: that it start when needed, that all components operate at a level sufficient to provide the minimum energy requirements of the shelter, and that it operate satisfactorily for the entire period of shelter occupancy.

Satisfactory operation, from the standpoint of delivering the required energy for the required length of time, can generally be assured by selecting industrial equipment with conservative ratings. Most industrial equipment is designed for several thousand hours of maintenance-free operation. Hence, two weeks of actual use, plus any reasonable exercising during the 10-year or more standby period would represent only a fraction of the potential life of the equipment.

Dependable starting, on the other hand, may be slightly more difficult to achieve. Dependable starting can be reasonably well assured if the fuel and ignition systems are functioning correctly and if there is adequate reserve energy available in the starting system. Frequent exercising continuous charging of the starting batteries, and a set of dry-charge starting batteries in reserve should assure dependable starting in an emergency.

### Deterioration Resistance

Any stored equipment which is expected to be operable for periods up to 10 years or more must be protected from various kinds of deterioration and surface fouling. Formation of corrosion, rust, rot, mold, gum, sludge, and sedimentation is undesirable. The ideal approach to preventing such degradation of the power system would involve the following measures: (1) minimize the use of materials susceptible to corrosion, etc., (2) provide an environment which prevents or inhibits rusting, etc., and (3) protect critical surfaces with high-quality, long-lived preservative materials.

### Simplicity

The avoidance of complex equipment and procedures will generally enhance the dependability of a system and will reduce the requirements for protection against time-based degradation. The simplest equipment that will do the job is also usually the lowest in first cost and easiest to install.

It is also highly desirable to eliminate the need for any servicing or other attention to the auxiliary power system during the two-week use period. This will minimize the possibility that an inexperienced or stressed person could cause a failure of any critical component of the system. However, it might require some added complexity to achieve the latter objective. Therefore, a compromise between maximum simplicity and minimum attention would appear necessary in most cases.

## PRESERVATION AND STANDBY MAINTENANCE

### Fuel Storage and Deterioration Characteristics

#### Fuels for Spark-Ignition Engines

Three distinctly different types of fuel can be used for spark-ignition engines: (1) gasoline (of course the most familiar), (2) liquified petroleum gas (LPG), and (3) a variety of virtually pure chemicals perhaps best typified by methyl and ethyl alcohols. Certain mixtures such as gasoline/alcohol blends can also be used. Each type has both advantages and disadvantages relative to emergency-power-generation requirements.

Gasoline. By and large, commercial gasolines cannot be expected to exhibit the kind of storage dependability required ideally for the community shelter program. This is by no means a condemnation. It is simply an indication that the normally high demand for gasolines, and consequent rapid turnover of finished products, makes it generally unnecessary for refiners to incur the expense of manufacturing highly storage-stable products. Exceptions may be common, but they probably are more fortuitous than intentional. For example, Ruf<sup>(1)</sup> \* reported in 1963 rather extensive Swiss experience in storing large quantities of commercial leaded and unleaded gasolines underground for periods up to 14 years. Essentially all of their gasolines gave good inspection-test results when fresh, and most were found virtually the same after 7 to 14 years. However, a few had deteriorated significantly. The point is that the implied level of dependability may not be great enough for a purpose such as shelter power generation.

At the same time, however, Ruf's article encourages hope that a "suitable" grade of gasoline can be stored with confidence for considerably longer than 10 years (perhaps indefinitely). The other but more limited gasoline-aging information available also supports this hope. Early French observations of gasoline stored for "several years" in steel or concrete

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\* References are listed on page 63.

reservoirs revealed that no significant deterioration occurred. Recent U. S. Bureau of Mines work<sup>(2)</sup> with drum storage, although stopped at 2 years, indicates that considerably longer storage stability can be achieved.

The following comments which appear in the Bureau's reports are most noteworthy:

1. When no sulfur or nitrogen compounds are present, essentially no gums are formed (during storage).
2. Complete desulfurization and saturation provide quite stable gasoline.

These comments correlate well with thoughts expressed by representatives of the refining industry consulted during this program. Additionally, it was remarked several times that leaded gasolines tend to give storage problems because of "lead precipitation" (probably due primarily to TEL hydrolysis by excessive water contamination).

In general, this premise seems reasonable: the "purer" the gasoline, the more dependable it should be for emergency-power generation. "Purity" in this context implies broadly the absence of non-hydrocarbon and/or unsaturated materials. Opinions expressed give the impression that gasoline which is sufficiently pure can be manufactured by the U. S. petroleum industry, in adequate quantities, and probably in an acceptable price range. This assurance, incidentally, stems largely from existent (and increasing) capabilities for hydrogen-involved refining processes which are enabling more and more refiners to produce high-purity products routinely.

An entirely different approach was also suggested. It was suggested that the gasoline used be a mixture of specified types of hydrocarbons, for example; 55 percent isooctane, 28 percent toluene, and 17 percent isopentane.

This particular formulation is essentially the hydrocarbon equivalent of 115/145 aviation gasoline. Without lead it would have about a 90-octane rating. This should be entirely suitable for emergency-power generation. The central problem, of course, would be to determine the purity requirements for each of the three components, within the context of dependability and cost considerations. It seems likely that commercial grades of these components would be adequate, since, in these cases, the "impurities" would themselves be essentially all hydrocarbons of comparable types with relatively good stability characteristics. The cost might not be unreasonable.

The pros and cons of gasoline-additive employment must also be taken into account. There should be no need for additives designed to modify gasoline-combustion processes. Otherwise, the apparent need for deterioration-preventing additives will vary inversely with the sophistication of the fuel-storage system. In general, the consensus of those consulted was this:

1. Matters should be so arranged that dependability of the gasoline will not hinge primarily on additive-type protection of fuel quality, the more dependable will be the overall fuel-supply system.
2. But even so, it might be well to employ modest amounts of certain additives as a degree of insurance (e.g., against untold effects of human errors in regard to fuel purity and/or malfunction of fuel-protection features of the storage arrangement).
3. The additives might include any or all of the following:
  - a. Antioxidant - to mitigate oxidative deterioration
  - b. Metal deactivator - to render innocuous any trace amounts of "dissolved metals" which might be carried over from the refining process or inadvertently introduced subsequently.
  - c. Metal passivator - to render innocuous the surfaces of new metallic tanks, pipes, etc.
  - d. Oxygen scavenger - if anaerobic storage is planned.

In any case, and granting that problems which could be caused by gasoline contamination are avoided, the crucial concerns are (1) the anticipated amount of gum formation in the gasoline during extended storage and (2) whether engine dependability might thereby be compromised. As implied during the foregoing discussion, a catastrophic amount of gum formation will not occur if "proper" precautions are taken initially in regard to fuel purity and design of the storage facility. But what is the scope of "proper" precautions, and is it necessary (or practical) to incur the extra cost of achieving some or all of them? The final answer to this question must come from studies outside the framework of this program. However, the remarks which follow will be of help.

Operation of spark-ignition engines is uniquely sensitive to non-volatile materials (gums) dissolved in the gasoline. This is an obvious corollary of the fact that a significant portion of the gasoline must be vaporized and mixed with a suitable proportion of air (i.e., carburetted) before it is inducted into the cylinders. Some types or portions of the non-volatiles may, of course, be entrained sooner or later in the vapor/air mixture and be carried into the cylinder. By and large, this can be presumed to have no significant consequence regarding emergency-power generation. The balance of the non-volatiles, on the other hand, can cause much trouble since they perforce must stay somewhere in the intake system. And since the temperature of the intake system rapidly becomes high, these materials tend to be transformed rapidly into tacky or hard carbonaceous masses (i.e., "intake system deposits"). If such deposits form excessively in certain parts of the intake system, especially in and around carburetor jets and intake valves, the efficiency of the engine can be drastically lowered, to the stalling point, and restarting is made difficult or impossible.

Unfortunately, there are no generally applicable relationships between engine operation and either intermediate concentrations of gums in gasoline or characteristics of the gums. The state of the art seems to reduce to this:

1. An existent-gum content around 40 milligrams per 100 milliliters of gasoline is too much
2. An existent-gum content of 6-7 milligrams per 100 milliliters is innocuous. (This is the specification-maximum range for all military gasoline purchases; domestic gasolines are normally produced under these same specifications.)(3)
3. Gasoline having amounts of existent gum between these two levels is to be viewed with suspicion.

Engine to-engine variations, coupled with little-understood variations in intake-system deposits arising from different gasolines, have made it impossible to develop definite "break point" correlations. The present specification limits are essentially estimates of the maximum existent-gum levels which can be expected to cause no troubles during extensive engine operations, regardless of the origin of the gasoline and/or nature of the gum. A comfortable safety margin is probably involved.

It may be argued that gasoline for shelter-power generation could be permitted to have gum contents up to perhaps 20 or 30 milligrams per 100 milliliters because build-up of intake-system deposits is time dependent. Only about 2 weeks of operation will be required of the emergency system. Therefore, during this short operating period a "high-gum" gasoline should cause no catastrophic problems. Consequently, needless expense might be involved in designing the fuel-supply system so as to insure minimal gum in the fuel at the time of need for emergency power. Although this is a quite logical proposition, unfortunately, there is no information by which it can be quantized with assurance.

Accordingly, there emerges one valid requirement for an optimum emergency-fuel-supply system based on gasoline:

THE EXISTENT-GUM CONTENT OF THE GASOLINE IN THE SYSTEM SHOULD NEVER EXCEED 6-7 mg/100 ml.

This requirement automatically provides the degree of dependability that is particularly crucial for such a system, and there is evidence that it can be satisfied at a reasonable cost.

There are several ways by which the above requirement can be satisfied. The two extremes would be as follows:

A. Start with commercial-grade gasoline with maximum existent gum of perhaps 3-4 mg/100 ml and provide nominal storage protection. The penalties would be:

1. Necessity for periodic gum analyses of each system (on the average of at least once per year)
2. Probable necessity for fuel replacement in each system on the average of at least once during a 10-year period.

The advantage would be:

3. Minimum initial cost.

B. Start with special-grade gasoline having essentially no existent gum (or gumming-prone constituents) and provide maximum storage protection. The penalty would be:

1. Relatively high initial cost.

The advantages would be:

2. Periodic gum-analysis effort could be reduced to a statistical sampling and longer-time basis.
3. Fuel replacement would probably be necessary in only a few systems during perhaps a 50+ year period.

Using Approach A but with the benefit of increasing degrees of storage protection, the frequency of fuel replacement necessity should be correspondingly reduced. But the implicit uncertainties about the storage behavior of commercial gasolines (i.e., unusual characteristics are not uncommon!) indicate that the sampling-and-analysis penalty might never be more than halved.

On the other hand, using Approach B but with decreasing degrees of storage protection, the essential effect would be simply to shorten the probable storage life of the fuel from 50+ to perhaps 10 years. Since the fuel involved would be relatively "inert", and also relatively -- or absolutely -- uniform in composition (unusual characteristics very rare or non existent), the sampling-and-analysis requirement would remain at a minimum level. This should also greatly simplify fuel-replacement planning if and when necessity becomes apparent.

All in all, Approach B seems more advantageous than Approach A.

To round out the picture, some consideration of analytical methods is also necessary. There are two distinct aspects of this matter: (1) procurement specifications (i.e., initial properties of the gasoline) and system-monitoring specifications (i.e., storage-consequent properties of the gasoline).

Procurement specifications will, of course, depend upon the quality and/or type of gasoline(s) selected for the overall shelter program. Other factors



being equal, there should be special concern about adherence to existent-gum, sediment, and water limitations, particularly for the gasoline as charged to each system. Otherwise, a question will persist about the usefulness of "potential gum" values (i.e., accelerated aging tests). The question is most pertinent to commercial gasolines; specially refined or specified-component gasolines should show up uniformly well. Nevertheless, a specification requirement on this score should be included. Its primary purpose would be to help keep gasolines with unusual characteristics out of the shelter program. Moreover, valuable correlations with aging experience may develop.

Monitoring specifications and routines, on the other hand, should center on detection of those types and degrees of change in the stored gasoline which are associated with deterioration. They may also be useful in this way for detection of storage-system deficiencies. The major deterioration "indicators" will be:

1. Existent gum
2. Sediment
3. Hydroperoxides
4. Color changes

However, details of the analysis routines will depend partly on storage features employed; e.g., necessity for hydroperoxide analyses might be obviated by anaerobic storage conditions. Also, determination of monochromatic light transmittance at one or more selected wavelengths might prove entirely adequate for the purpose, rather than separate determinations of the individual factors listed.

The latter possibility is suggested by Phillips Petroleum Company's success in using changes in transmittance of 350-mu light as a means of assessing the thermal stability of jet fuels.<sup>(4)</sup> The point is this: the deteriorative changes which occur in jet fuels exposed to high temperature are assumed to be much the same chemically as those which occur (much more slowly, of course) in gasoline at ambient temperature. Therefore, for gasoline also, light transmittance at selected wavelengths should be uniquely affected by the presence of certain gum precursors and gum constituents, as well as by sedimentaceous impurities. A portable and simple-to-operate testing kit based on this principle undoubtedly could be devised. If proven to be sufficiently accurate, this expedient could effect a great saving in the cost of the overall monitoring effort.

#### Fuels for Compression-Ignition Engines

Unlike the situation for spark-ignition engines, only one type of fuel merits consideration for compression-ignition (diesel) engines. This fuel comprises relatively high-boiling petroleum distillates composed primarily of lightly branched and saturated aliphatic hydrocarbons; a minimum cetane rating

of about 40 is needed, but a rating of about 60 would be desirable. The degree of branching relates primarily to the freezing point of the fuel, a secondary consideration under the storage conditions envisioned for shelter power systems.

The available information pertinent to storage stability of diesel fuels is somewhat more encouraging than that for gasolines. This is primarily because the instability criteria are considerably less stringent in one important respect. The gum content (i.e., nonvolatile, but soluble components) of a diesel fuel apparently has little or no effect on engine performance. That is, diesel fuel in its liquid state is injected directly into the engine's combustion chamber; a pre-volatilization step is not involved as with gasoline engines. And, there are no indications that even sizeable amounts of soluble gum in the fuel causes significant combustion problems. It does stand to reason that there must be a practical upper limit for gum content (because the combustion characteristics of gum certainly must differ significantly from those of the balance of the fuel, e.g., contribute to carbon residue). However, the practical implication is that catastrophic levels of gum are neither encountered in commercial diesel fuels nor are generated therein during storage. The Swiss experience<sup>(1)</sup> with up to 13 years' underground storage is the best confirmatory evidence available in this connection.

This matter of gum and gum formation is critical for two other reasons however:

1. Gum formation is a primary indicator of fuel deterioration in diesel fuel just as it is in gasoline. That is, gum is generated in some relationship both to initial quality or composition of the fuel and to the conditions of storage.
2. The gum-formation processes lead eventually to generation of materials which are insoluble in the fuel. That is, the more extensive the degree of gum formation during storage, the more likely that such insoluble materials will be generated.

Insoluble materials in diesel fuel, whatever the sources, can definitely hamper engine operation by causing clogging, sticking and/or wear in the close-tolerance fuel-injection system. And by virtue of their usually high molecular weight, organic insolubles will contribute to carbon fouling of the combustion chamber.

Of course, in-line filtration of the fuel is normally employed to remove most of the particulate matter (ca.  $> 5 \mu$ ). And certainly, provision for such filtration, as a matter of insurance, should be made in the shelter power system. But one important question remains. This concerns the ease of filtration of fuels which contain significant amounts of "organic sediment". Such insoluble materials tend to be amorphous and waxy, and under some circumstances they can rapidly clog filtration units.

It is therefore obvious that the fuel-supply system must be so arranged

that a catastrophic amount of organic sediment will not develop in the fuel during storage and that it will provide protection against contamination. Filtration should not be expected to compensate, in this connection, for either fuel of low initial quality or for excessive compromise in protection afforded during storage. That is, the dependability factor should be a dominating consideration.

Accordingly, there emerges the key requirement for an optimum emergency-fuel-supply system based on diesel fuel:

THE SEDIMENT (OR INSOLUBLES) CONTENT OF DIESEL  
FUEL IN THE SYSTEM SHOULD NEVER EXCEED 0.1-0.2  
mg/100 ml AND 5 Microns MAXIMUM PARTICLE SIZE.

These contaminant levels are accepted under military cleanliness requirements for aircraft fuels which are considered to provide "excellent" fuel system reliability<sup>(5)</sup>. Considerably higher sediment levels (2-3 mg/100 ml) do not necessarily cause filter plugging, as demonstrated by tests run by the Naval Engineering Experiment Station<sup>(6)</sup>. The suggested limit would automatically provide a desirable and possibly necessary degree of dependability for an emergency system.

As with gasoline, there is evidence that diesel-type fuel of requisite quality can be obtained at a reasonable cost. The essential requirement is that the fuel be essentially free of nonhydrocarbon and/or unsaturated components. Examples of present commercial products which would appear to be adequately "pure" in this respect include aviation kerosenes (Type A, JP-5, etc.) and various petroleum solvents.

Fortunately, considerable information about storage stability of jet fuels has been accumulated in programs concerned with thermal stability problems. Although studies seldom extended for more than 2 years, trends revealed in these programs, together with the Swiss experience with commercial diesel fuels per se, provide almost overwhelming evidence that 10+years of dependable storage life can be expected of a diesel-type fuel which is (1) sufficiently pure at the outset and (2) given reasonable protection during storage.

Otherwise, the overall problem is very nearly the same as that for gasoline. That is, both would be relatively pure mixtures of hydrocarbons and thus would require virtually the same considerations and compromises regarding additives, conditions of storage, and monitoring.

Incidentally, it is interesting to note that the Soviets have commented that their jet fuels have been stored 6 - 7 years without deterioration<sup>(7)</sup>. No details are available about the particular fuels and the storage conditions available. At any rate, they attribute at least part of this stability to anti-oxidant properties of certain sulfur-and/or nitrogen-containing materials which

occur naturally - and possibly uniquely - in their straight-run distillate fuels. Similarly, the apparent inhibitive effects of natural impurities in certain petroleum products has been noted by various U. S. authors<sup>(8)</sup>. Thus, a logical argument seems to exist against a "high purity" requirement for fuels considered for emergency-power generation. However, several counter-acting facts must be kept in mind:

1. The lack of assurance that the natural impurities in any particular petroleum fuel will provide a predictable degree of antioxidant protection...without rather extensive study of that particular fuel.
2. The obvious necessity to involve fuels at minimum cost from many different refiners in the present program.
3. The obviously great desirability to involve in the program only fuels of highly uniform quality, so as to minimize the eventual monitoring requirements.
4. The frequent correlations found between aging instability and high polar-compound contents of fuels.

All other factors equal, there are three inherent differences between gasolines and diesel-type fuels which favor the latter for emergency-power generation:

1. Diesel-type fuels are the less volatile. Accordingly, if vented storage conditions are employed, they pose the least chance for serious loss of "quick starting" components.
2. Diesel-type fuels provide more energy per gallon. A given storage volume of diesel fuel contains more potential energy for power generation because of its higher density and the higher efficiency of the diesel engine compared with gasoline in a spark-ignition engine.
3. Diesel-type fuels would appear to possess considerably longer potential storage life. This is an hypothesis, but it seems logical and may deserve experimental study. It follows from the fact that fuel deterioration in storage comprises a sequence of time-dependent chemical reactions. The key point is the assumption that fuel-insoluble "organic sediment" is generated from fuel-insoluble gum, i.e., that gum-formation is the first step, and must proceed to some significant extent before generation of "organic sediment" begins. So, if  $t_g$  = time to formation of the maximum permissible gum (in gasoline), it seems obvious that  $t_s$  (time to formation of maximum permissible organic sediment, in diesel-type fuel) will be significantly greater. In other words:

$$t_s = t_g + \Delta_t, \text{ or } \Delta_t = t_s - t_g$$

The magnitude of  $\Delta_t$  could have, therefore, an important bearing on shelter program economics. Unfortunately, there is no available information which can be used to estimate  $\Delta_t$  values with assurance for various fuel/storage combinations. Accordingly, experiments along this line - based of necessity on accelerated aging, however - could be highly advantageous in the development of practical parameters for the shelter program.

### Fuels for Gas Turbines

The fuel requirements for gas turbines are much less stringent than those for compression-ignition and spark-ignition engines. The gas turbine is capable of burning any of the commercially available petroleum fuels. However, the use of leaded gasoline is not recommended. Leaded gasoline will cause a high rate of lead oxide deposition on the turbine blades, in the combustion chamber, and in the regenerator. This will seriously shorten turbine useful life and could also reduce power output and efficiency.

### Fuel Storage Facilities

Many techniques are available to the shelter designer for storing liquid fuels. Those techniques considered most applicable to community shelters will be discussed here. In selecting a storage technique, the important considerations are: prevention of deterioration, preservation of combustion qualities, and meeting the requirements imposed by state and local fire and safety regulations. Regarding the latter, it is reasonable to expect that in some instances it will be necessary to obtain special permission in order to use the most satisfactory storage system.

There are two basically different fuel storage techniques which may be followed for an emergency standby system: active storage and long-term storage. In an active fuel-storage program a fuel would be replaced or replenished at regular intervals, and the storage tank requirements would be relatively uncritical. In a long-term fuel-storage program the storage system would be designed to preserve the fuel for the longest possible period of time, and the fuel quality would be checked at regular intervals so that the first signs of deterioration could be detected before there was serious degradation of fuel qualities. The time intervals between inspection and/or replacement of the fuel would vary considerably with the type and quality of the fuel as well as with the storage conditions.

Vented Underground Fuel-Storage Tank. Many fuel tanks for conventional emergency standby engine-generator sets and for other stationary engine power plants are located above ground. An aboveground vented tank is the simplest and least expensive type of fuel storage facility. However, the hazards of blast, firestorm, and vandalism make the aboveground tank too unreliable for most community shelter applications. Furthermore, it is well known that fuels will store longer in tanks buried in the ground because of the reduced "breathing" of the tank caused by the expansion and contraction of the fuel due to temperature variations. This "breathing" results in fuel vapor loss and a greater amount of atmospheric air, oxygen and moisture coming in contact with the fuel. For these reasons the vented underground tank will be considered as the minimum fuel-storage facility appropriate for community shelters.

Figure 1 illustrates an underground vented fuel-storage tank. The vent should not be located next to a building or under the overhang of a building. Local fire regulations may require that the fuel line between the tank and the shelter slope toward the fuel tank. If this is the case, the arrangement shown would have to be modified or special permission would have to be obtained. Permitting gravity feed of the fuel from the tank to the shelter does involve the risk of draining the entire fuel supply into the engine enclosure if the shutoff valve is accidentally left open and there is a leak in the piping system within the shelter. However, the simplicity of gravity feed is a significant advantage in terms of both cost and reliability, and close control over operation of the fuel system should minimize the risk of flooding.

Flexible sections are included in the fuel lines, both between the fuel tank and the shelter and between the shelter floor and the prime mover, to reduce the danger of failure in the lines due to the relative movement of these components. A charging pump is provided in the system in the event that minor blockage in the fuel system should prevent normal gravity flow to the "day tank". The "day tank", mounted on the engine, reduces the number of fuel lines which must be run between the main fuel tank and the power source, provides for additional settling and straining of insoluble contaminants from the fuel, and provides the proper fuel pressure head regardless of the amount of fuel in the storage tank and of the orientation of the storage tank with respect to the prime mover.

Sealed Underground Fuel-Storage Tanks. Experience has shown that fuel storage life can be further increased by sealing the underground tank. Sealing the tank will limit the amount of moisture and oxygen to which the stored fuel is exposed and will also limit the rate of evaporation. To change a vented storage system, as shown in Figure 1, to a partially sealed system requires only replacing the vent cap with pressure and vacuum relief valves which are designed to seal at pressures up to 2 psig and to admit air at a vacuum of about 1/16 psig. If the proper ratio between air space and fuel volume is used, valves of this type will reduce tank breathing considerably. Commercial fuel tanks are generally pressure tested at 5 psig; consequently, 2 psig would not be an excessive pressure. In some instances, fire regulations may require the addition of a safety relief valve with a pressure setting of about 2-1/2 psig. A further refinement of the partially sealed fuel storage tank system would be the addition of a desiccant canister a few feet above ground level in the vent line. If this is done, even the small amount of air entering the air-vapor space above the fuel would contain only a negligible amount of moisture.

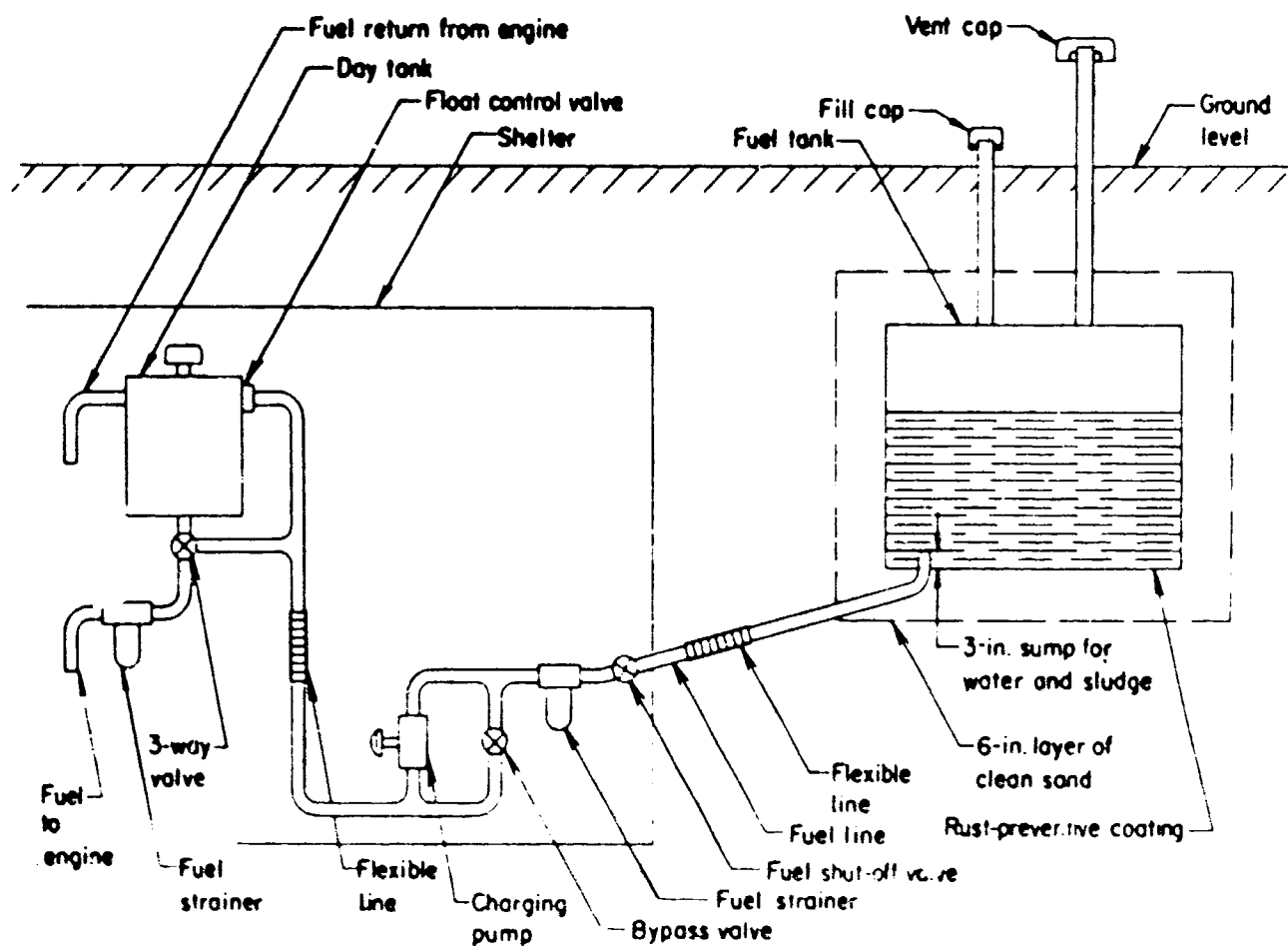


FIGURE 1. UNDERGROUND VENTED FUEL-STORAGE SYSTEM

Figure 2 shows an underground sealed fuel-storage tank with positive nitrogen pressure above the fuel. This type of fuel-storage system is frequently referred to as a nitrogen-blanket system. The nitrogen blanket completely prevents air and water vapor from coming into contact with the fuel. A minimum nitrogen pressure of about 1/2 psig should be maintained for expansion of the fuel due to seasonal temperature variations by filling the tank to only 90 or 95 percent of its capacity. The tank would have to be equipped with a pressure relief valve to prevent the internal pressure from exceeding the design limit. A vacuum relief valve would be required to prevent damage to the tank in case the nitrogen supply should be exhausted and subsequently the liquid level in the tank would be lowered by a decrease in temperature or by removal of fuel from the tank.

The storage system could be checked for serious leaks by simple observation of the rate of pressure loss from the nitrogen tank. Small leaks, however, might be masked by pressure fluctuations resulting from temperature changes. A small surge chamber located between the nitrogen tank and the pressure reducer could be a useful aid in determining the presence of small leaks. All but the most minute leaks could be detected if the tank valve were closed and the rate of pressure decline in the surge chamber were observed over a 10-minute period. The nitrogen consumption of such a system would have to be determined after installation. Because pressurized nitrogen-blanket storage systems are seldom used, such an installation might require special approval from state and local authorities.

Figure 3 shows a sealed underground storage tank for LPG. LPG is supplied and stored in pressure vessels as a liquid. The storage pressure varies with the ambient temperature and can approach 200 psi in warm weather. The liquid must be vaporized by heat addition before it can be passed through a carburetor and into an engine for combustion.

There are two methods in common use for withdrawing LPG fuel from the storage tank during engine operation. These two methods are vapor withdrawal and liquid withdrawal. The vapor withdrawal method is illustrated in Figure 3. In this system the fuel vaporizes in the tank above the liquid surface. The heat required for vaporization is supplied by the earth surrounding the tank. The vapor, which is above atmospheric pressure, flows through the fuel line, a primary regulator, a dry-type filter, an electric shut-off valve, and finally through a secondary regulator, to the carburetor. As long as there is sufficient new vapor formed in the tank to supply the engine requirements, the vapor withdrawal system will function satisfactorily.

It has been found through experience that a 500-gallon tank half full and buried at least 2 feet below the frost line will vaporize 8-1/2 gallons per hour at 40 F, and a half-full 1000-gallon tank under the same conditions will vaporize 15 gallons per hour. A 100-hp prime mover operating at full load will consume about 12 gallons per hour and will require a total fuel supply of about 2,200 gallons for a 2-week period. If this fuel were stored in a 2,800-gallon tank buried at least 2 feet below the frost line, the vaporization rate should be more than adequate.

The liquid-withdrawal method requires an artificial source of heat for vaporization of the fuel. The fuel is piped in liquid form to the engine and passed through a vaporizer unit which includes both primary and secondary regulators. The usual source of heat for the vaporizer is hot water from the engine



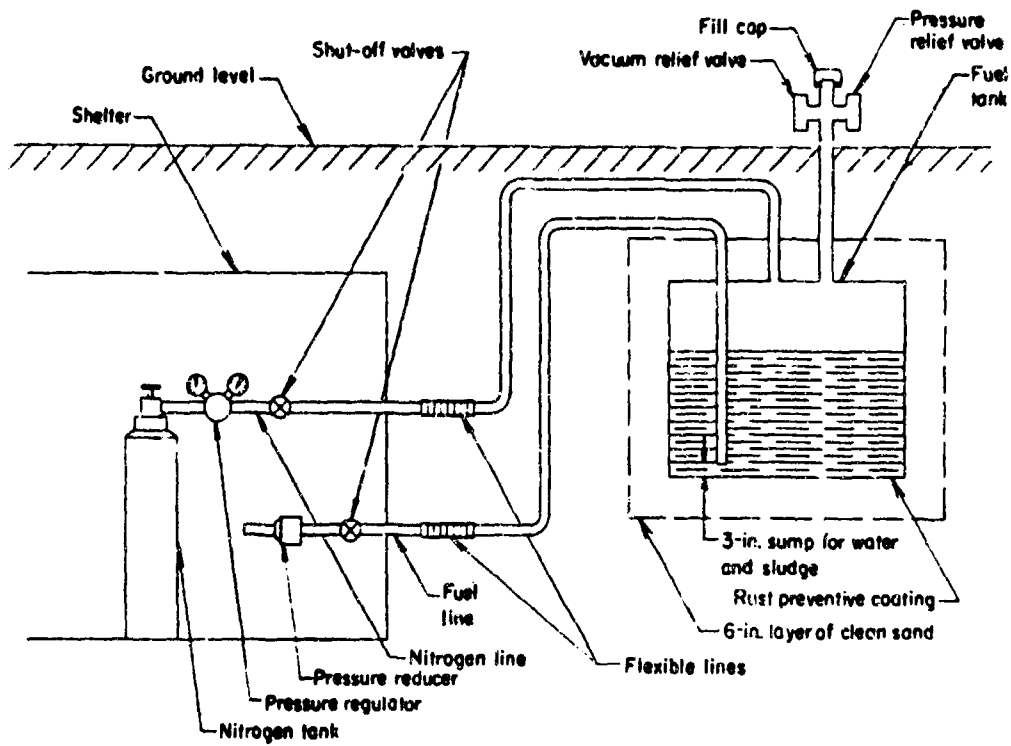


FIGURE 2. UNDERGROUND SEALED FUEL-STORAGE SYSTEM WITH POSITIVE NITROGEN PRESSURE

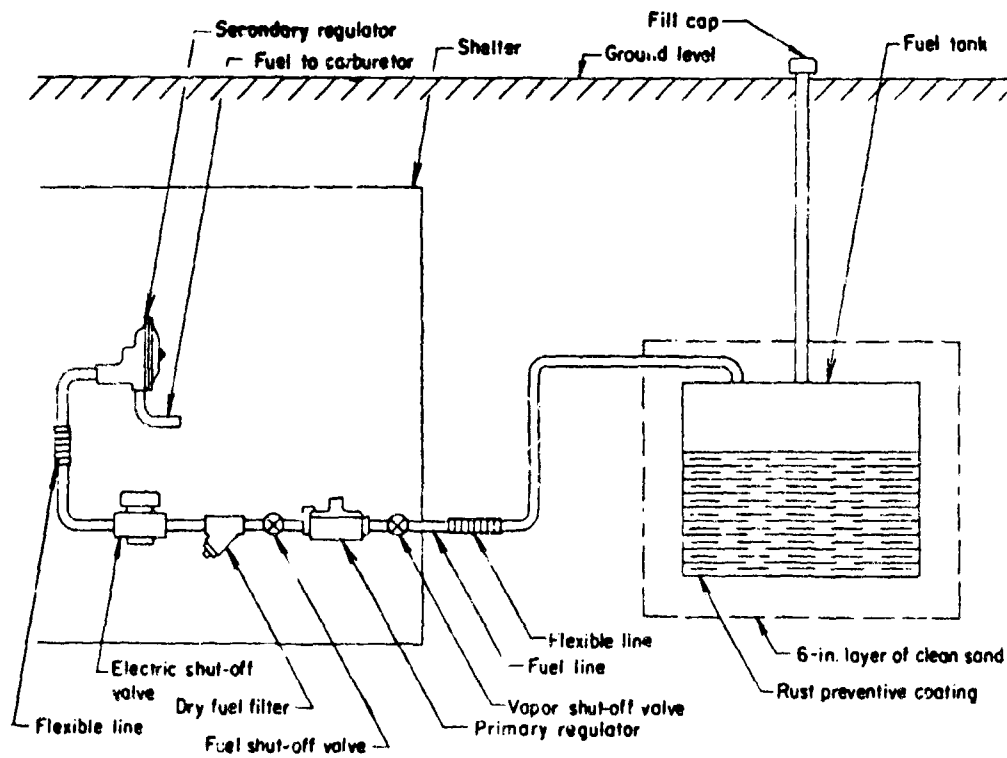


FIGURE 3. UNDERGROUND LPG FUEL-STORAGE SYSTEM

jacket; however, a problem arises in starting and warming up the engine before sufficient jacket heat is available. Smaller engines can frequently be started and warmed up on the vapor which naturally forms in the tank above the liquid. This would depend on the volume of the space above the liquid and on the ambient temperature. For maximum reliability, an external source of heat would have to be provided for starting and warming up the engine. A battery-powered electric heating element or a home "handyman"-type propane torch could be used to provide the necessary emergency heat.

The estimated storage life of LPG is quite long compared with that of other petroleum-based fuels. The LPG tank is sealed and pressurized, and if it is properly purged and filled initially, there should be no air or water in the system.

LPG is heavier than air and thus will seek and settle in low places. Positive means must be provided to sweep out any leakage to avoid any explosion hazard. Numerous codes and regulations govern the installation of the LPG fuel systems, and these should be followed rigidly.

### Summary of Fuel Storability

Figure 4 shows in summary form the storage life of the various fuels which have been discussed, in conjunction with the fuel storage techniques most applicable to shelter power systems. These data are, of necessity, based on relatively sparse information and, in some cases, educated guesses. The storage life values on this chart may appear in some cases to be greater than commonly accepted values; however, the general emphasis has been on underestimating to account for the many uncertainties.

These data, though in some cases somewhat speculative, are considered conservative enough to be used in devising fuel-system maintenance routines. Where the data are not particularly supported by actual storage experience, it is advisable to plan a sampling and analysis routine to monitor the deterioration of the fuel in storage. In the case of the LPG and special-blend fuels, the ultimate storage life is unknown and may extend much beyond 20 years under ideal conditions.

### Storage of Prime Movers

#### Basic Requirements of Standby Storage

The principal objectives of any standby storage program should be to prevent deterioration of the stored material and to assure starting and operating reliability. To a certain extent, accomplishing the first objective will assist

## Fuel Storage Technique

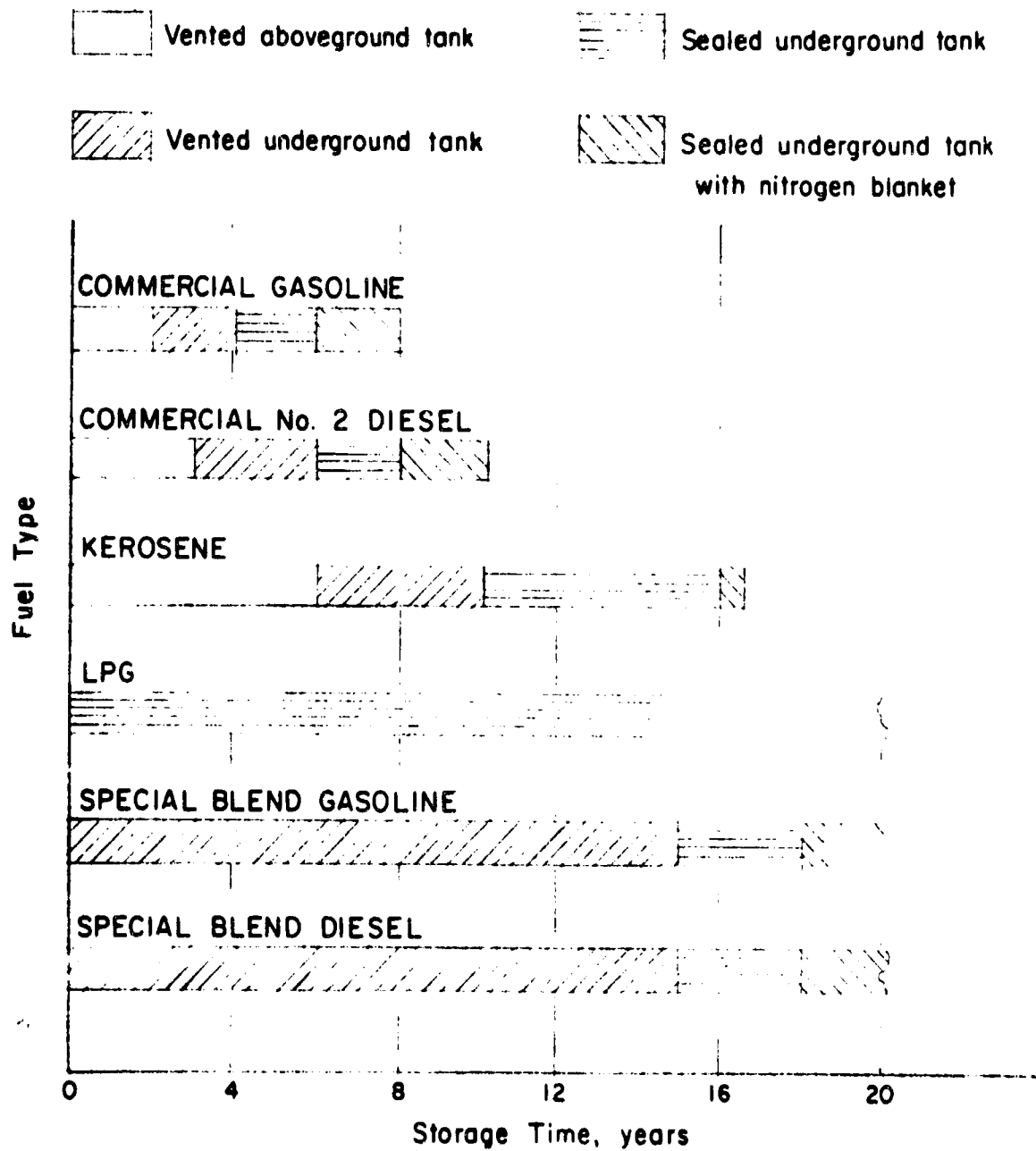


FIGURE 4. ESTIMATED STORAGE LIFE OF REPRESENTATIVE FUELS

in accomplishing the second. However, there are aspects of starting and operating reliability which are independent of long-term deterioration. A third objective can be added to the two mentioned above, namely, to minimize the cost and complexity of the preservation and reactivation methods. This objective is particularly pertinent to the OCD shelter program.

Most, if not all, prime movers and supporting equipment are made of materials which are subject to deterioration to one degree or another from natural destructive forces. The equipment cannot remain useable indefinitely, in storage or in use, unless the critical components and surfaces are protected in some manner from these destructive forces. Although these forces include such chemical, physical and biological agents as acids, salts, sunlight, heat and cold, oxygen, ozone, fungi, etc., under general storage conditions water is by far the most damaging. It is the one factor common to most deterioration, acting in combination with or in support of other forces to produce deterioration.

Since water vapor is normally present in the air, it would be difficult to exclude moisture from materials in storage without considerable expense and effort. Fortunately, it is not necessary to maintain a completely dry atmosphere to avoid corrosion. Figure 5 illustrates the effect of humidity on the corrosion of steel. These data were obtained by exposing mild steel in the pickled condition to various humidity conditions for a one-year period and measuring the weight loss due to corrosion. At high humidities weight loss was significant, but below 50 percent humidity the weight loss in one year was not measurable. These results have been essentially confirmed by tests of actual equipment stored for up to 5 years in different humidity environments.<sup>(9)</sup>

There are several different methods commonly used to protect materials and equipment from moisture-caused deterioration. Among these are protective coatings, packaging, chemical impregnation, and dehumidification. Each method has merit for special purposes, but none can be said to be the one best solution for all storage problems.

Reliability of starting and operation can be impaired by failing to replace worn-out components, to maintain adequate fluid levels in lubrication and cooling systems, and to maintain storage batteries at an adequate charge level.

Equipment stored for standby use will, of course, experience no wear. However, frequent exercising, with its characteristic start-and-stop operation, can result in abnormal wear patterns which must be taken into consideration when performing maintenance, particularly with a piston engine. Fluids such as lubricating oil and cooling water, which tend to be consumed during operation or lost through vaporization and evaporation, must be periodically replenished to forestall equipment failure due to their absence in an emergency. Frequently the problem can be partially alleviated by initially supplying an excess of the fluid so that the time between refills can be lengthened. Under certain circumstances, a sufficient excess may be provided to allow for all normal losses in use and in stand-by storage. An engine depending on an electrical starting

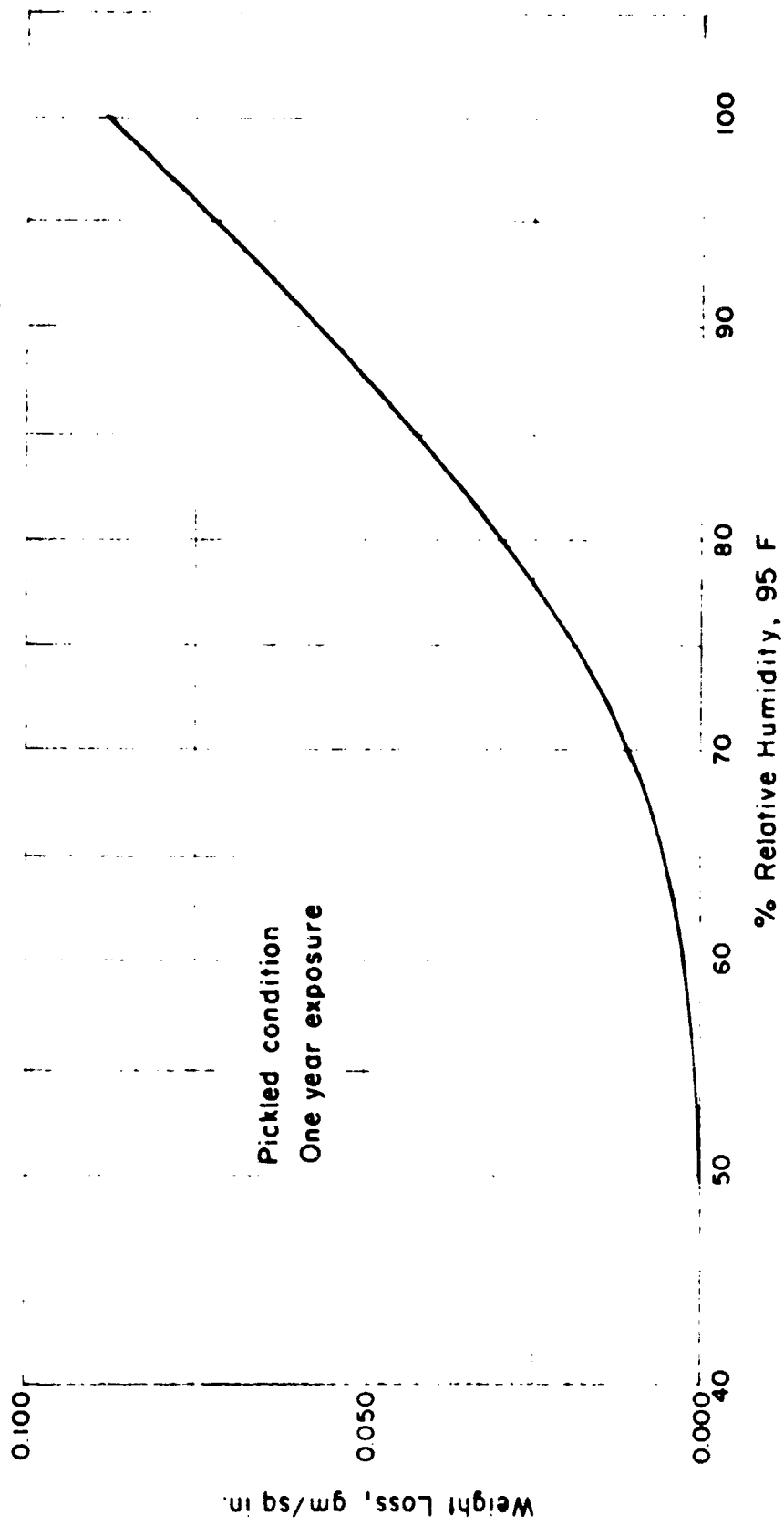


FIGURE 5. EFFECT OF HUMIDITY ON THE CORROSION OF STEEL

system would be useless if the battery supplying the power for starting were found to be run down. An inadequately charged battery might result from age, from over charging, from malfunction of the charging system, or from loss of commercial electric power during the stand-by period. These situations must all be guarded against or at least appropriately monitored.

There is another factor which can significantly affect starting and operating reliability but which is more difficult to guard against or to plan for. Failure of any component or system may occur due to an inherent structural or material fault, or to improper assembly. Fortunately, such failures do not occur very often, and when they do they may be discovered immediately during a rigorous break-in and check-out run of the whole auxiliary power system.

In evaluating the different problems and methods of deterioration control and maintenance, the peculiar and specific requirements of the application must be considered. For instance: Will the equipment be called upon to respond immediately in an emergency? If not, how much time will be available for re-activation? What personnel with what skills will be required? What personnel and skills will be available for in-storage maintenance? Under what conditions (i.e. hazards, stress) will reactivation take place? What kind of service will be required of the equipment when reactivated? Ultimately, the choice of any storage technique will depend largely on these requirements and on the estimated equipment and maintenance costs.

#### Specific Storage Characteristics of Prime Mover Systems

The Prime Mover. The most critical component of the shelter power system, in terms of preservation for standby use, is the engine. Piston engines are susceptible to corrosion on vital, highly machined surfaces such as cylinder walls, valve seats and guides, bearings, and gear faces, and on electrical contacts such as ignition points and distributor contacts. Unchecked corrosion at any of these surfaces is likely to result in hard starting, serious loss of power, or possibly complete failure due to seizing or to lack of electrical continuity. Gas turbines have significantly fewer critical machined surfaces that would be subject to corrosion, and hence, should be easier to maintain in standby storage from that standpoint.

The accumulation of gum, varnish, or sediment in fuel, lubrication, and cooling system passages, in piston ring grooves, and on mechanical or hydraulic control system components is a second major source of potential trouble in an engine in standby storage. If deposits of any kind build up in sufficient quantity in these areas, the ultimate result would be a deterioration in the performance of these systems of components serious enough to cause partial or complete failure of the engine. Again, gas turbines being simpler than piston engines, would be less susceptible to this type of failure.

The Starting System. Prime-mover starting systems have individual storage problems. In battery-electric starting systems the battery will lose its charge with time unless it is maintained with a trickle or variable-rate charger, or unless it is stored in the so-called dry-charge condition. In the dry-charge condition the electrolyte is stored separately from the battery in a sealed

plastic container. Batteries stored in this manner are said to have at least a 10-year shelf life. However, when a dry-charge battery is activated, it is capable of delivering only about 2/3 the power of the same battery fully charged; consequently, an oversize battery must generally be provided to assure an adequate level of starting reliability. Good quality, lead-acid batteries, maintained on a trickle charge should have a storage life of 5 to 10 years. Nickel-cadmium batteries might have a storage life under similar circumstances of at least 15 years.

Hydraulic starting systems depend on the maintenance of a pressure charge in an accumulator. Aging effects on the accumulator diaphragm or seals may cause that charge to be lost over a period of time if provision is not made for replenishment. Most hydraulic systems can be equipped with a manually operated pump, which minimizes the accumulator charge problem and provides an unlimited number of starting attempts in an emergency.

The Cooling System. Prime-mover cooling systems depending upon water as the cooling medium must be protected from the effects of rust, corrosion, and sedimentation, any of which could render the systems inoperative. The two main techniques for cooling system preservation are (1) mixing corrosion-inhibiting compounds with the coolant and (2) storing the coolant separately from the cooling system. Air-cooled engines and gas turbines are, of course, free from this problem.

Generators and Motors. The principal problems encountered in the storage of generators and motors are oxidation of switch contacts, relay contacts, and armature commutator rings; corrosion and mildew of insulation and seals; and deterioration of the lubricant in the bearings. Preservations cannot be applied to the electrical contact surfaces because they would interfere with electrical continuity. Materials highly resistant to oxidation may be used, but it still may be necessary to clean the surfaces before the emergency use. Corrosion and mildew-resistant materials should be used where possible and moisture should be excluded from the interior of the generator or motor. The lubricant used in the bearings should be capable of long-term storage without deterioration and should cover all surfaces of the bearing.

#### Current Stand-By Maintenance Practice

Periodic Exercising. Conventional emergency standby power systems are almost universally maintained in a state of readiness by frequent periodic exercising. In conjunction with the exercising, which is sometimes as often as once a week, the systems are inspected and serviced regularly. The frequent exercising generally results in maintaining a film of oil on bearing surfaces, cylinder walls, etc., and in reducing the accumulation of moisture in the system. The exercising also is a deterrent to the build-up of sludge and sediment in fuel, lubrication, and cooling systems, and it provides a periodic indication of faulty components or component wear. The regular inspection and servicing provides both an opportunity for detecting and correcting external deterioration and an additional check on equipment malfunction and wear.

With periodic exercising it is not necessary to utilize any extensive preservation treatments for the engine, unless the environment is exceptionally humid or unless the engine is exposed to the weather. A majority of emergency standby equipment installations are in buildings where the humidity is generally relatively low and temperature variations are small. A corrosion inhibitor may be used in the coolant but the lubricants and fuel are usually standard operational products. Exposed surfaces will be kept clean, and where corrosion has a tendency to start, the surfaces may be either oiled or painted.

A typical procedure for the "active" maintenance of an emergency power system on standby might be as follows:

1. Use conventional lubricants in engine and conventional coolant with rust inhibitor added
2. Maintain starting battery on trickle or variable-rate charger
3. Exercise engine and equipment twice a month
  - (a) start and warm up engine at fast idle
  - (b) run at 80-percent load or higher for at least 1/2 hour
  - (c) observe and record key performance data
4. Inspect critical components at each exercising
5. Perform detailed inspection and maintenance annually: change engine oil, coolant, and filters
6. Replace or recondition questionable components and materials when indicated.

It should be noted that most conventional emergency standby power systems are expected to start immediately and to deliver full power in just a few minutes when an emergency occurs. There is great need, consequently, for a high state of readiness. In fact, many standby systems start automatically when commercial power fails and can assume full load in a matter of seconds. The criticality of instant starting in installations of this type has exerted a strong influence on the established pattern of standby maintenance. Another important factor in most conventional installations is that experienced personnel are readily available to perform the standby maintenance. Hospitals, communications facilities, hotels, apartment buildings, and many other similar installations have building superintendents or maintenance men who are generally capable of maintaining and operating emergency standby power equipment.

Mothballing. Whereas periodic exercising may be considered as "active" maintenance, a completely "passive" approach to standby maintenance would be mothballing. All of the military services have used and are using the mothballing technique for preparation of equipment for shipment or dead storage. The Navy's "mothballed fleet" probably affords the best example of this storage technique. The general approach to mothballing an engine is to completely seal the engine in an enclosure not much larger than the engine itself and to place a desiccant within the enclosure or to circulate dry air through the enclosure. The enclosure may be a metal housing or can, a strippable plastic sprayed over a framework or directly on the engine, or a moisture and vapor-proof wrapping



material. If a desiccant is used a means must be provided to show when the desiccant material is used up, and the desiccant must be replaceable with a minimum disturbance of the enclosed seal.

In addition to the outer wrap, mothballing also requires the use of preservatives on the engine itself. The lubricants used in the cylinders, bearings, gears, etc., are of high quality and capable of retarding corrosion and other forms of deterioration. All other surfaces subject to corrosion are also protected, either by paint or by other appropriate preservatives.

A typical procedure for mothballing a prime mover might be as follows:

1. Drain crankcase; flush and refill to operating level with type P-10 preservative.\*
2. Connect fuel line to portable fuel tank filled with good grade of fresh fuel; run engine on fast idle until warmed up; run at 3/4-speed no load and switch fuel line to portable tank with type P-9 preservative; continue running until engine begins to misfire (spark ignition engine) or blue smoke appears in exhaust (diesel engine); immediately shut engine off.
3. Allow engine to cool to under 100 F then atomize type P-10 preservative into cylinders (through spark-plug openings or through intake valve) while cranking engine with starter; spray type P-10 preservative into valve chambers; blow VCI crystals into cylinders and valve chambers.
4. Clean air cleaner with type P-10 preservative.
5. Fill cooling system with type P-3 preservative before engine preservation run; drain when preservation is completed.
6. Spray type P-1 preservative on all unpainted exterior surfaces.
7. Spray ignition insulation compound on electrical wiring and electrical components.
8. Seal all openings with pressure sensitive tape.
9. Wrap entire engine and generator with water-vaporproof barrier material.
10. Place desiccant and humidity indicator inside enclosure, with indicator visible from outside through clear plastic window.
11. Inspect every 30 days for condition of desiccant and replace when used up.

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\* See Appendix B for list and description of preservatives.

The chief disadvantages of mothballing are that it requires a considerable amount of time and effort to prepare a piece of equipment for storage and to reactivate that same equipment from storage. Some technical skill is required for both operations. Mothballing is intended to provide a dead-storage technique that will minimize deterioration losses with only minor emphasis on standby readiness.

Dehumidified Warehousing. In recent years mothballing has been replaced at many government storage installations by the use of dehumidified warehouses. This is particularly true where short-notice reactivation may be required. It has been found through a number of experimental programs that the cost of storing equipment in dehumidified warehouses can be significantly less than the cost of mothballing or other storage techniques. Furthermore, the equipment thus stored generally deteriorates less and is essentially ready for use instantly.

An excellent example of dehumidified warehousing is the Army's prepositioned materiel program<sup>(10)</sup>. This program has to do with the storing of the materiel required to support a particular type of military action as close to the potential scene of action as is tactically feasible. The personnel for whom this equipment is intended may be based hundreds or even thousands of miles away, or may not even be mobilized. The plan is to bring the equipment and personnel together with a minimum of reaction time in the event of an emergency. Dehumidified warehouses are used almost exclusively for this program, and it is anticipated that each vehicle stored in a given warehouse can be made combat-ready in two hours.

A typical procedure for dehumidified warehouse storage of a power system on standby might be as follows:

1. Follow steps 1 thru 7 as outlined for mothballing
2. Fill cooling system with water plus corrosion inhibitor
3. Maintain relative humidity at 40 to 50 percent
4. Visually inspect a 10-percent sample every 30 days
5. Perform functional test (exercise and then represerve) on 10-percent sample every year.

#### Pertinent Storage Experience

Canadian Army Outdoor Storage Program.<sup>(11)</sup> An experimental outdoor storage program for military vehicles, conducted by the Canadian Army during the 1953 to 1962, was mentioned in a previous Battelle report to OCD\*. The engines of these vehicles were preserved in approximately the manner outlined in this report for mothballing, except that no VCI was used, the valve compartments were not opened for preservative application, and the exterior surfaces of the engines were not treated with preservatives. All of the vehicles reactivated and service-tested after the 6 to 8 years of storage were found to be in good condition and to perform approximately as required.

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\* Summary Report to Office of Civil Defense, "Minimum Requirements for Auxiliary Power Systems for Community Shelters", from Battelle Memorial Institute (July 15, 1964).

U.S. Navy Cyclic Preservation Tests <sup>(12)</sup>. Tests were conducted in 1952 and 1953 at the U.S. Naval Supply Research and Development Facility at Bayonne, New Jersey, to evaluate existing cyclic preservation techniques for materials-handling equipment. Gasoline engine-powered fork-lift trucks were included in these tests. It was concluded that, with limited preservation of the engine, 30-day exposure periods between exercising are adequate for outdoor storage in climatic conditions similar to that of Bayonne, New Jersey. Periods up to 60 days may be adequate in locations with less severe climatic conditions. The engines were preserved in the following manner: crankcase filled with Military Specification MIL-L-644 preservative lubricating oil; cooling system filled with inhibited ethylene glycol U.S. Army Specification 4-1116; and U.S. Army Specification 3-182 ignition seal sprayed on wires, spark plug, distributor, and engine block.

U.S. Navy Storage Environment Test Program <sup>(9)</sup>. A 5-year storage-test program was conducted at the U.S. Naval Civil Engineering Laboratory in Port Hueneme, California, in the period 1957 to 1962. In this program duplicate assemblages of military equipment, including diesel generator sets and gasoline-engine trucks and jeeps, were stored in five different types of storage environments. These were: open air, shed with one side open, standard closed warehouse, warehouse maintained at 50-percent relative humidity, and warehouse maintained at 40-percent relative humidity. Two significant observations made in this test program are that no rust or corrosion resulted during the five years storage in either dehumidified warehouse and that the cost of maintaining 40-percent relative humidity was twice the cost of maintaining 50-percent relative humidity.

It was also noted from the test program that total storage cost for the diesel generator set was least in the 50-percent relative humidity warehouse with domestic treatment; for the truck and jeep it was least in the standard warehouse with domestic treatment. "Domestic treatment" is a cursory preservation treatment performed generally by the manufacturer or supplier and consisting of using type P-1 preservative on all exterior non-machined ferrous-metal surfaces; using regular oils and greases in crankcase, transmission, differentials, etc.; taping all openings shut.

Marine Corps Dormant Exercising Technique <sup>(13)</sup>. In the mid 1950's the Marine Corps experimented with an exercising technique called "dormant exercising". This technique consisted of operating the engine and vehicle drive train without supplying fuel and ignition. With preservative oils and greases in the system, the starter motor was actuated to turn the engine over (at about half idling speed) for 5 to 15 seconds. This was found to be long enough to build up sufficient oil pressure to distribute oil throughout the lubrication system. Preservative oil was also pumped through the fuel system and distributed into the combustion chambers by the action of the pistons. Check valves were installed in the spark-plug holes to relieve engine compression in order to decrease the load on the starter.

This exercising method provides for the periodic redistribution of preservative oils within the engine without the disadvantages of normal exercising such as accumulation of residual corrosive gases from combustion, diluting or washing away of preservative oil coatings by raw fuel, and deterioration of the preservative qualities of the preservative oils by heating. More recent references to "dormant exercising" were not found, so it is not known whether the method was judged successful or not.

Army Ordnance Dehumidified Storage Project<sup>(14)</sup>. A project was conducted by the Ordnance Tank Automotive Command Industrial Division to evaluate the requirements and effects of dehumidified storage of Ordnance material. The project, conducted in the period 1955 to 1958, involved establishing dehumidified warehouse facilities at the Lima Ordnance Depot, Lima, Ohio, and storing combat tracked vehicles in these warehouses for periods up to 3 years. The general conclusions from this project were: Ordnance material can be maintained in serviceable condition in dehumidified warehouses for years with little or no preservation; the cost of maintaining the building and dehumidifying equipment is relatively small; and two 100-cfm dynamic dehumidifiers are adequate for maintaining 35-percent relative humidity in a space of 100,000 cubic feet.

Long-Term Exposure of Aircraft Hydraulic Systems<sup>(15)</sup>. An investigation was recently conducted by the SAE Long Term Storage Panel to assess the effects of long exposure of aircraft hydraulic systems to a variety of natural environmental conditions. Hydraulic equipment, such as hydraulic pumps and motors, hydraulic cylinders, and accumulators, were removed from certain World War II aircraft that had crashed in locations involving extremes of environmental conditions. One aircraft had lain on the North African Desert for 17 years under temperature extremes of 26 to 120 F and an average humidity of 10 to 36 percent. Another was found on the Greenland icecap after 23 years of exposure under temperature extremes of -80 to +38 F and an average humidity of 55 to 70 percent. Two others were examined in a Central American jungle after 5 years and 24 years exposure under temperature extremes of 71 to 88 F and an average humidity of 90 to 100 percent.

The equipment exposed to the arctic and desert environments was found to be in good shape with the hydraulic pumps and motors capable of meeting new-unit operational specifications. The desert environment caused the accumulator diaphragm to stiffen resulting in loss of the accumulator charge, but the accumulator charge from the arctic environment was a normal 325 psi. Equipment from the jungle environment was found to be deteriorated, but most of it was still functional and able to meet new-unit specifications. For further comparison, similar hydraulic equipment was removed from aircraft stored for five-to ten-year periods in the open desert at an air base in Arizona. This equipment was found to be in excellent condition and able to meet new-unit specifications.

Army Ordnance Nutrient Mothballing<sup>(16)</sup>. A potentially inexpensive technique for mothballing stored equipment has been experimented with by the Army Ordnance Corps in Louisiana. The technique involves erecting hutments over machinery and equipment stored in standard warehouses or shop buildings, and maintaining low relative humidities within the hutments by the use of small dehumidifying units. The walls and ceilings of the hutments are constructed of polyethylene-coated burlap consisting of 40-inch widths sewn together and strung on steel cables stretched over the area to be enclosed.

The 10-oz burlap is extrusion coated on each side with a 4-mil film of polyethylene which provides a good water-vapor-transmission barrier. The walls of the hutment are fastened to the floor by two-by-fours imbedded in mastic. The equipment stored within these hutments is treated with only a light coating of oil before storage. This storage system has been judged to be reasonably effective and economical; however, it would appear to be more suited to protecting equipment and machinery in situ than as a permanent long-term storage technique.

## STANDBY MAINTENANCE ROUTINES FOR SHELTER POWER SYSTEMS

### Fuel-System Maintenance

#### Selection of Fuels

A large number of potential fuels were discussed in a previous section of this report. However, study of the important characteristics of these fuels, particularly potential storage life, commercial availability and cost, revealed that the number of fuels could be logically narrowed down to six. These six are: commercial regular-grade gasoline (about 90 octane), special-blend gasoline (high purity for long storage life), commercial-grade No. 2 diesel oil, special-blend diesel oil (high purity for long storage life), kerosene (aviation quality), and liquified petroleum gas (LPG). The storability of each of these fuels was presented in Figure 4.

A number of petroleum companies were contacted in the Columbus, Ohio, area to establish the approximate costs of the commercially available fuels in 2,000-gallon quantities delivered to the site. A number of direct contacts with petroleum refiners has established an approximate range for the premium cost that might be expected for the special-blend fuels. The cost estimates received from these various sources were averaged and resulted in the following values which were used in this study.

<u>Fuel Type</u>	<u>Fuel Cost, ¢ per gallon</u>
Commercial-grade gasoline	14
Special-blend gasoline	18
Commercial No. 2 Diesel oil	12
Special-blend diesel oil	15
Kerosene	13
LPG	17

To establish the fuel requirements of each power-system installation and maintenance routine, the fuel-consumption rates of each type of engine were taken from the manufacturers' catalogs. These fuel-consumption rates, based on a representative 55-kw engine-generator set, are as follows: gasoline engine - 6.63 gph, diesel engine - 4.88 gph, and LPG engine - 6.10 gph. Using these fuel-consumption rates, the total fuel required for the projected two-week emergency period and for the various exercising routines discussed in the following section of this report was computed for each engine type. The results of these computations are shown in Table 1. The values in this table include an additional 10 percent in each case to cover the possibilities of fuel loss due to vaporization during the standby period, human error during the filling and exercising procedures, unexpected leakage, and unanticipated additional power requirements.

TABLE 1. FUEL REQUIREMENTS FOR SHELTER POWER SYSTEMS

Requirement	Engine and Fuel Type		Compression-Ignition Diesel oil, kerosene
	Spark-Ignition Gasoline	Spark-Ignition LPG	
Emergency fuel, gallons	2453	2266	1804
Exercise fuel, gallons/year			
Every week	190	175	140
Every 6 weeks	32	29	23
Every year	11	10	8

NOTE: Values are based on a 55-kw engine-generator set operating at full load and including a 10-percent cushion.

#### Selection of Storage Facilities

In a previous section of the report the various fuel storage facilities considered appropriate for community shelter power systems were discussed. These were: a vented underground tank, a sealed underground tank, and a sealed underground tank with nitrogen blanketing. Any of these fuel tanks can be used with any of the fuels being considered in this study with the exception of LPG. LPG must be stored in special tanks because the pressure of the LPG fuel in storage can be as high as 200 psi, depending on the ambient temperature. The normal fuel tank is tested to only 5 psi.

Manufacturers of fuel tanks were contacted to determine the approximate purchase cost of various size tanks, and contractors were contacted to determine the approximate cost of burying these tanks in the ground. The cost of installing the tanks turned out to be quite variable from one contractor to another. Because of the desirability of assuring that the fuel tank itself has a very long storage life, at least 15 years or more, it was decided to use fairly high estimates for tank installation to account for the extra care that would be required for long life.

Figure 6 shows estimated fuel tank purchase and installation costs based on the storage capacity of the tank. The LPG tank costs are considerably higher than the costs for standard fuel tanks because of the high fuel pressures these tanks must withstand. The tank-only costs represented by these curves include delivery to the site. The installation costs of both the standard and LPG tanks include: excavation, coating the outside of the tank with a bituminous mastic material, and use of sand as backfill. If, upon further evaluation, it is deemed necessary to go into a more expensive coating for the tank and/or to cathodic protection, the installation costs might be considerably higher than those shown in Figure 6.

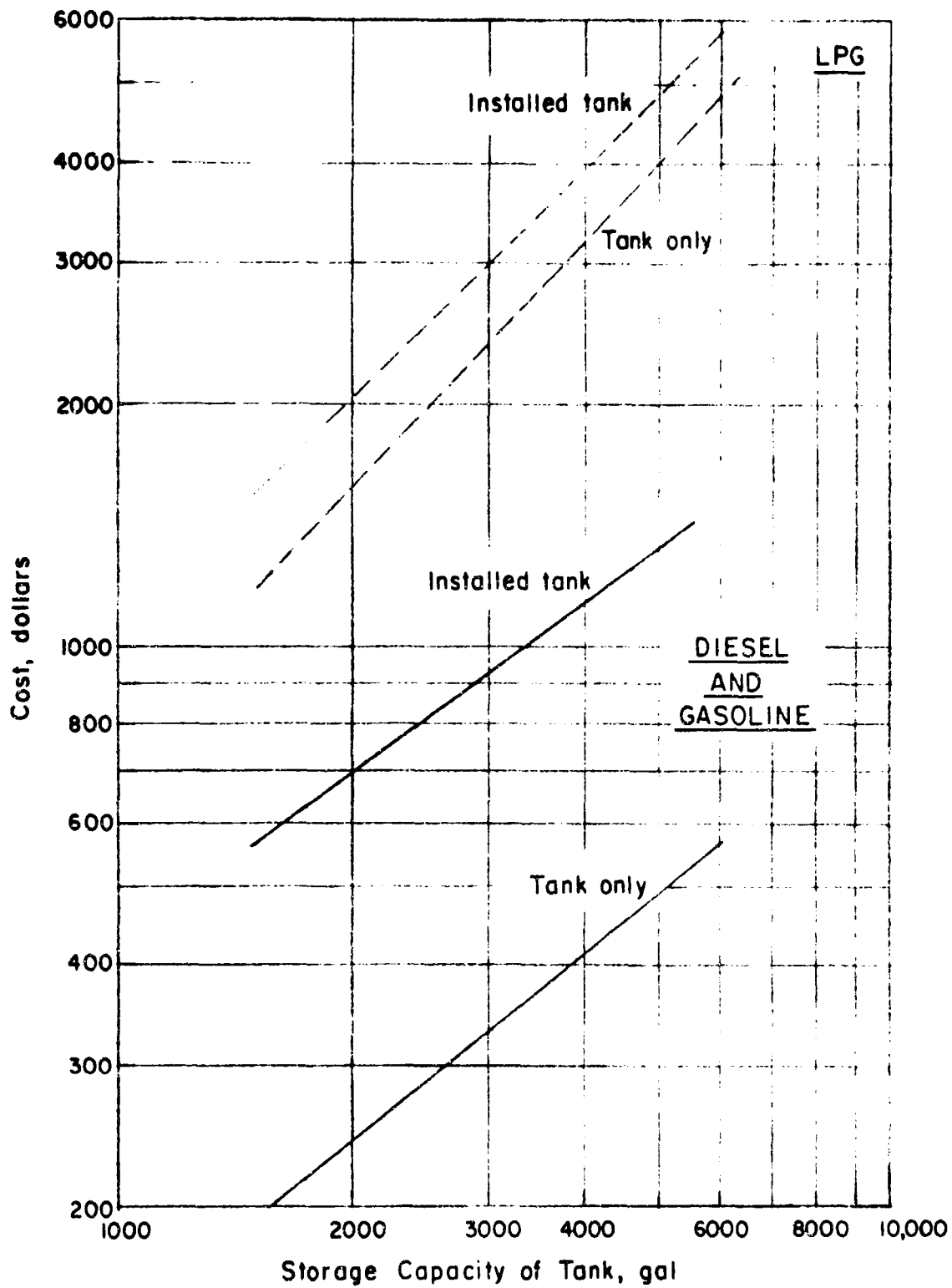


FIGURE 6. ESTIMATED FUEL TANK PURCHASE AND INSTALLATION COSTS

The data shown in Figure 6 do not include the cost of piping and other accessories such as the breathing valves for sealed tanks and the nitrogen supply system for a nitrogen-blanket fuel-storage technique; consequently, separate estimates were made for the costs of this equipment. The piping system would consist merely of the fuel line from the tank to the engine room, including a shut-off valve and a flexible section and extra fuel filters. The cost of this piping system, including materials and labor, was estimated as \$30.00. The breathing-valve system for the sealed tank was described in a previous section of this report and would include pressure and vacuum relief valves, a safety relief valve, and a desiccant canister. The total cost of these, components including the cost of installation, was estimated as \$80.00.

A nitrogen-blanket system would consist of the nitrogen supply tank or tanks, a pressure regulator capable of regulating to as low as 1/2 psi, and the necessary piping between the nitrogen tanks and the fuel tank. The cost of the regulator and the piping, including installation, was estimated as \$80.00. The purpose of the nitrogen-blanket system is to provide a continuous positive nitrogen pressure over the fuel in the tank. To accomplish this it would probably be necessary to have some small rate of supply from the nitrogen system to make up for small leaks and for the loss due to breathing of the tank. Since experience with an actual system of this type was not available, it was necessary to make a rather crude estimate of the amount of nitrogen gas that would be consumed by such a system. The cost of the tank of nitrogen, which contains 300 cubic feet at atmospheric pressure, is only about \$5.00; hence, the total cost of a fuel storage system of this type cannot be too sensitive to the amount of nitrogen that is used. For a rough estimate it was decided to base the system costs on a rate of consumption that would represent one full tank every six months. The cost for the nitrogen including the labor of changing tanks was then estimated as \$20.00 per year.

#### Fuel Storage Routines

The importance of the fuel-storage facility to the storage life of the fuel dictates that fuel-storage routines be organized according to the method of storage. Each fuel would be handled slightly differently in each of the three storage facility types being considered in this study. The principal variables in handling the fuel are as follows: (1) frequency of sampling and analyzing, (2) source of exercising fuel, (3) frequency of replenishing exercising fuel if taken from storage tank, and (4) frequency of replacing emergency fuel.

The sampling and analyzing could be done on a contract basis with the contractor collecting as well as analyzing the samples. The analysis would be for existent gum and sediment. An estimate of \$40 per sample seems reasonable for this study, although it is entirely possible that in the future a simplified analysis technique could be worked out for less cost, perhaps one that could be performed at the shelter site.

The periodic exercising of the shelter equipment could be accomplished either using fuel from the storage tank or using fresh fuel. Fuel stored under conditions which promote long storage life should probably not be disturbed. Therefore, when a sealed underground tank is used for storage, fresh fuel should be used for exercising. If fuel is used from the storage tank for exercising, it should be replaced at fairly frequent intervals to avoid both excessive ullage and the necessity for an excessively large storage tank.



The emergency or main supply of fuel should be replaced at intervals consistent with the storage life data presented in Figure 4. In the periodic sample, analyses indicate unacceptable degradation before scheduled replacement, the fuel should be replaced sooner. As experience is accumulated in maintaining fuel systems on standby, it may be possible to extend the storage periods beyond the current scheduled periods.

The fuel storage routines devised for evaluation in this study are shown in the following three tables. Table 2 shows the routines devised for a sealed underground storage tank. Table 3 shows the routines devised for a vented underground storage tank. Table 4 shows the routines devised for a sealed underground storage tank with a nitrogen-blanket system.

TABLE 2. SUGGESTED PROCEDURES FOR FUEL STORAGE ROUTINES  
USING A SEALED UNDERGROUND TANK

Fuel Type	Storage Procedures
Commercial-grade gasoline	<ul style="list-style-type: none"> <li>o sample and analyze every 2 years</li> <li>o exercise with fresh fuel</li> <li>o replace emergency fuel every 6 years</li> </ul>
Commercial No. 2 diesel	<ul style="list-style-type: none"> <li>o sample and analyze at 4th year and 6th year</li> <li>o exercise with fresh fuel</li> <li>o replace emergency fuel every 8 years</li> </ul>
Kerosene	<ul style="list-style-type: none"> <li>o sample and analyze every 4 years</li> <li>o exercise with fresh fuel</li> <li>o replace emergency fuel every 16 years</li> </ul>
Special-blend gasoline	<ul style="list-style-type: none"> <li>o sample and analyze every 5 years</li> <li>o exercise with fresh commercial fuel</li> <li>o no fuel replacement necessary</li> </ul>
Special-blend diesel	<ul style="list-style-type: none"> <li>o sample and analyze every 5 years</li> <li>o exercise with fresh commercial fuel</li> <li>o no fuel replacement necessary</li> </ul>
LPG	<ul style="list-style-type: none"> <li>o exercise using fuel from storage</li> <li>o replenish exercise fuel every year</li> <li>o no fuel replacement necessary</li> </ul>

TABLE 3. SUGGESTED PROCEDURES FOR FUEL STORAGE  
ROUTINES USING A VENTED UNDERGROUND TANK

Fuel Type	Storage Procedures
Commercial-grade gasoline	<ul style="list-style-type: none"> <li>o sample and analyze every year</li> <li>o exercise using fuel from storage</li> <li>o replenish exercise fuel every 2 years</li> <li>o replace emergency fuel every 4 years</li> </ul>
Commercial No. 2 diesel	<ul style="list-style-type: none"> <li>o sample and analyze every 2 years</li> <li>o exercise using fuel from storage</li> <li>o replenish exercise fuel every 3 years</li> <li>o replace emergency fuel every 6 years</li> </ul>
Kerosene	<ul style="list-style-type: none"> <li>o sample and analyze every 3 years</li> <li>o exercise using fuel from storage</li> <li>o replenish exercise fuel every 3 years</li> <li>o replace emergency fuel every 10 years</li> </ul>
Special-blend gasoline	<ul style="list-style-type: none"> <li>o sample and analyze every 3 years</li> <li>o exercise with fresh commercial grade fuel</li> <li>o no fuel replacement necessary</li> </ul>
Special-blend diesel	<ul style="list-style-type: none"> <li>o sample and analyze every 3 years</li> <li>o exercise with fresh commercial fuel</li> <li>o no fuel replacement necessary</li> </ul>

TABLE 4. SUGGESTED PROCEDURES FOR FUEL STORAGE ROUTINES  
USING A SEALED UNDERGROUND TANK WITH NITROGEN BLANKETING

Fuel Type	Storage Procedures:
Commercial-grade gasoline	<ul style="list-style-type: none"> <li>o sample and analyze at 4th and 6th years</li> <li>o exercise with fresh fuel</li> <li>o replace emergency fuel every 8 years</li> <li>o replace nitrogen supply every year</li> </ul>
Commercial No. 2 diesel	<ul style="list-style-type: none"> <li>o sample and analyze at 4th, 6th and 8th years</li> <li>o exercise with fresh fuel</li> <li>o replace emergency fuel every 10 years</li> <li>o replace nitrogen supply every year</li> </ul>
Kerosene	<ul style="list-style-type: none"> <li>o sample and analyze every 4 years</li> <li>o exercise with fresh fuel</li> <li>o replace emergency fuel every 16 years</li> <li>o replace nitrogen supply every year</li> </ul>
Special-blend gasoline	<ul style="list-style-type: none"> <li>o sample and analyze every 7-1/2 years</li> <li>o exercise with fresh commercial fuel</li> <li>o no fuel replacement necessary</li> <li>o replace nitrogen supply every year</li> </ul>
Special-blend diesel	<ul style="list-style-type: none"> <li>o sample and analyze every 7-1/2 years</li> <li>o exercise with fresh commercial fuel</li> <li>o no fuel replacement necessary</li> <li>o replace nitrogen supply every year</li> </ul>

## PRIME MOVER MAINTENANCE

### Selection of Equipment and Facilities

The Prime Mover. The study of prime-mover deterioration characteristics revealed no clearly superior prime mover for the purpose. Of the prime-mover types evaluated, the LPG and gasoline-fueled spark-ignition engines and diesel engine are the only ones appropriate for consideration in the shelter program. The gas turbine, though it has some attractive advantages for stand-by storage, is too high in first cost and fuel consumption and is relatively unavailable in the size range of interest for present consideration.

An electric generator directly coupled to the engine output shaft was chosen as the most appropriate means for converting the engine shaft power to useful work in the shelter. A generator system is less expensive and has more flexibility than other power-transmission systems. Power-dependent shelter equipment can be run alternatively by commercial electric power in an emergency if available. At any rate, a certain minimum of electric power is essential for lights and communications equipment.

A battery-electric starting system and an engine-mounted radiator cooling system were chosen as representative systems because of their low first cost, simplicity, and availability. Other starting and cooling systems would have merit for particular circumstances, but by far the most frequently used and least expensive systems involve electric starting and radiator cooling. Auxiliary equipment to be provided with the prime mover includes a low-oil-pressure cutout, a high-water-temperature cutout, an overspeed cutout for failure protection, oil pressure and oil temperature gages, a water-temperature gage, a running-time meter, an exhaust system, and a fuel day tank.

A 100-hp prime mover was selected as a representative size upon which to base estimates for acquisition and maintenance costs. A 100-hp prime mover directly driving an electric generator will produce 50 kw of 110-v, 60-cycle, 3-phase AC power at the output terminals on continuous duty and 55-kw on emergency stand-by duty. The stand-by rating can be used for shelter application because of the short duration of the occupancy period.

Engine-Room Ventilation and Moisture Control. The auxiliary power system, as part of a community fallout or blast shelter, must be isolated and in many cases even sealed from the ambient environment. This poses certain problems of ventilation and moisture control during the standby period. The most severe case would be an underground, single-purpose installation. This case will be assumed for the representative system discussed in this section of the report.

Fumes from the fuel and gases resulting from the battery-charging operation would tend to build up to dangerous levels in the engine room unless some means were provided to remove these gases and fumes. The more hazardous constituents of these gases, being heavier than air, would accumulate on the floor of the engine room; consequently, a ventilation system drawing contaminated air from the lowest level in the engine room and discharging it to the outside would be necessary. An air inlet located in the ceiling opposite the ventilation discharge would supply fresh air to replace the expelled air.

The accumulation of hazardous fumes and gases is not likely to be very rapid; hence, only a small ventilation rate would be necessary. A complete air change once every few hours should be entirely adequate. The 55-kw power system is estimated to require an engine room of about 10 feet by 12 feet by 8 feet high, or roughly 1,000 cubic feet. A ventilating blower operating continuously should have a capacity of about 6 cfm. However, a blower operating on an on-off cycle would have a considerably longer life; hence, a blower with a capacity of about 60 cfm at a moderate static pressure head, operating for 10 minutes every 2 hours, appears to be a reasonable selection for the representative power systems. The motor driving this blower should be an explosion-proof motor because of the presence of potentially explosive gases in the engine room exhaust air. The power consumption of this ventilation system is estimated to be about 1/2 kw-hr per day.

An underground engine room would tend to be a damp place, regardless of the geographical location or of the season of the year. For instance, relative humidities of over 80 percent are normally encountered in caves, mines, and missile silos. Consequently, some means for reducing the moisture level in the engine room during standby would be desirable, no matter what standby maintenance procedures were used. There are a number of ways of removing moisture from an enclosed space; however, two methods stand out as particularly appropriate for the shelter power system on standby: mechanical refrigeration and dry desiccant.

The ordinary household-type dehumidifier is a good example of the use of mechanical refrigeration for humidity control. The unit, consisting of a small refrigeration system and a fan, extracts moisture from the air by condensing it on the evaporator coils.

The dry-desiccant type of dehumidification system is used where moisture in large spaces is to be controlled, where closer control over the humidity level is desired, where very low humidities are to be maintained, and where ambient temperatures are below 60 F. This type of dehumidifier functions by passing the air through a material (the desiccant) which absorbs the moisture. The desiccant is regenerated (or reactivated) by passing heated outside air through it during a different period in the cycle. The dehumidified air and the reactivating air are circulated in two completely separate air-flow systems. Only a small amount of heat is generated in the moisture-removal process, and the hot, humid air circulated during the reactivation process is discharged to the atmosphere, thus posing no moisture or heat-removal problems.

The performance of any dehumidifier depends on the desired humidity conditions within the shelter, the temperature and humidity conditions outside the shelter, the moisture permeability of the shelter walls, the air infiltration and/or ventilation rates, and any sources of moisture such as combustion or water leaks within the shelter.

An example of the actual performance of a refrigeration-type dehumidifier in a fallout shelter environment was given in the final report on a study conducted for OCD on moisture in survival shelters.<sup>(17)</sup> In this study a 1/3-hp dehumidifier was placed in an underground shelter of waterproofed concrete block construction and with an enclosed volume of about 1000 cubic feet. The ground temperature outside the shelter was about 65 F. At the beginning of the test the shelter relative humidity was 90 percent and the dry-bulb temperature was 66 F.

After 10 days of continuous operation, the humidity leveled off at 45 percent and the dry-bulb temperature at 69 F. The power consumption would be about 9.4 kilowatt hours per day.

On the basis of catalog engineering information from a manufacturer of dry-desiccant type dehumidifiers, the smallest available model would be capable of maintaining the same humidity and temperature conditions as for the example above in a space of about 5000 cubic feet operating continuously. Since the engine room space is only 1000 cubic feet, the desiccant dehumidifier would only be operating 20 percent of the time. At a rated power consumption of 950 watts the total power consumption for the desiccant dehumidifier would be about 4.6 kw hours per day.

Power System Purchase and Installation Costs. Estimated costs of the major power system equipment are given in Table 5. These cost estimates do not include the cost of the space the system would occupy or the cost of the fuel and fuel system. The purchase costs are generally catalog prices and do not reflect potential trade or quantity discounts. Installation costs of the engine-generator sets were estimated as approximately half the purchase costs. Other installation costs were estimated using a labor cost of \$6.00 per hour.

TABLE 5. ESTIMATED SHELTER POWER SYSTEM  
PURCHASE AND INSTALLATION COSTS

Component	Purchase Cost, \$	Installation Cost, \$
Gasoline Engine-Generator Set	3,695	1,900
LPG Engine-Generator Set	3,920	1,960
Diesel Engine-Generator Set	5,895	2,950
Starting System; batteries, battery charger, wiring	160	20
Auxiliary Equipment; running time meter, overspeed cutout, water and oil temperature gages, muffler and exhaust duct, fuel day tank, etc.	450	30
Engine Room Ventilation System	75	30
Refrigeration-Type Dehumidifier	80	--
Dry-Desiccant-Type Dehumidifier	635	40

In gathering the information for Table 4 no attempt was made to include all items of equipment or material. Therefore, the purchase and installation cost estimates are only approximate. An effort has been made to use conservative values. Since these cost estimates are primarily for comparison purposes, any inaccuracies or omissions will have only a small bearing on the final results in reference to alternative standby maintenance plan costs.

Break-In Run. It is advisable to give every power system a thorough break-in run, regardless of the type of prime mover selected and the method of standby maintenance to be followed. For the break-in run the engine should be operated at or near full load for a continuous period of about 25 hours. It is preferable to use the actual shelter load for breaking in the engine, although an artificial electrical load bank would be acceptable. During the break-in run, all systems and components should be thoroughly tested and closely observed. Engine operating data should be observed and recorded as a check on the anticipated performance of the engine and to provide a set of "normal" data against which to compare future engine operating data.

The break-in run would very likely show up any defects in the power system equipment or in the installation. The break-in run could also be used to train personnel who would be responsible for the standby maintenance and/or for operation of the unit during an emergency.

### Active Standby Maintenance

Active standby maintenance is based principally on periodic exercising and inspection and provides a high degree of readiness of the equipment. The cost of an active maintenance program is primarily dependent upon the frequency of the exercising and inspections. In actual practice exercising frequency varies from as often as weekly to as little as once every six weeks. Most manufacturers and users of the equipment recommend weekly exercising. However, there is no well-established evidence as to what frequency would be optimum for any given installation. Therefore, for the purpose of this study two active maintenance schedules were considered, one specifying frequent exercising and the other infrequent exercising.

Frequent Exercising. Table 6 shows the routine devised for the frequent exercising, active-maintenance program. As noted in the table, the power system would be exercised and inspected once a week and serviced once a year. No special preservation materials or treatments are required. Standard operational lubricants and coolants would be used.

Operating and inspection data would be recorded in a log book beginning with the initial break-in run of the engine and equipment. Pertinent operating data to be recorded would include: generator output voltage, current, and frequency; engine-cooling-water temperature; and lubricating-oil pressure and temperature. Inspection data would include: cooling-water level, crankcase-oil level, battery electrolyte level and specific gravity, battery cell voltage, and general appearance of all components and systems.

The same procedures (as outlined in Table 6) would apply equally to gasoline-, LPG-, and diesel-fueled engines. The quantity of fuel used during exercising would, of course, be different for the different engine types, but the amount of lube oil and coolant used during the annual servicing would be about the same for each. As noted in the table, the diesel engine would require fuel filter changes as well as oil filter changes.

TABLE 6. SUGGESTED PROCEDURES FOR ACTIVE MAINTENANCE PROGRAM WITH FREQUENT EXERCISING

Operation	Frequency	Labor Hours	Material Used
<b>Maintenance</b>			
o change engine oil and coolant, replace oil filter and fuel filter (diesel engine), clean air cleaner, lubricate motor, generator, and pump bearings, use conventional lubricants, greases, and coolant (with rust inhibitor added)	annually	2	lubricants, grease, coolant
o maintain starting battery on trickle charge	continuously	none	2 kw-hr/day
o maintain low humidity in engine room with refrigeration-type dehumidifier	continuously	none	10 kw-hr/day
o replace or recondition worn or failed parts and maintain proper lubricant, coolant, and battery electrolyte levels	as needed	--	--
<b>Exercising</b>			
o start engine and allow to warm up at fast idle	weekly	1/2	fuel
o run at 80 percent load or higher for 1/2 hour	weekly	1/2	fuel
o observe and record performance data	weekly	--	--
<b>Inspection</b>			
o inspect engine, generator, fuel system, exhaust system, starting system and other critical components for leaks or other evidence of malfunction or deterioration	weekly	1	none
o perform detailed inspection including electrical system checks on generator and motors, specific gravity and voltage of batteries, and mechanical condition of all components of installation	annually	2	none



Infrequent Exercising. Table 7 shows the routine devised for the infrequent exercising, active-maintenance program. A period of six weeks between exercising and inspection is a somewhat arbitrary choice, but it is believed that this exercising frequency would still be sufficient to provide the reliability benefits of periodic exercising.

In general the operating, inspection, and maintenance procedures for the infrequent exercising program are the same as those for the frequent exercising program. The recorded data and observations assume an increasing importance because of the less frequent opportunities to observe the system performance and to inspect for deterioration. As the power-system installation ages, it may become necessary to shorten the period between exercising and/or inspection. The need for doing this would be indicated by signs of significant deterioration or engine starting difficulties.

#### Passive Standby Maintenance

Passive standby maintenance is based on the use of deterioration-resisting materials, protective surface coatings, and a low-humidity environment. In passive maintenance greater effort is expended to prepare the equipment for the standby period so that less effort will be required for periodic exercising and inspection. The cost of a passive maintenance program is apportioned between the labor and material costs involved in preparing the equipment for standby and the cost of maintaining the low humidity environment.

Table 8 shows the routine devised for the passive-maintenance program. As noted, each system would be visually inspected every 3 months and exercised and represerved every 12 months. Variations in the procedures required by the different engine types are noted. In general, however, the procedures are the same for the gasoline-, LPG-, and diesel-fueled engine types.

As with the active-maintenance programs, the visual observations during inspections and the performance data recorded during the yearly exercising are important in indicating the condition of the system. Shortening of the inspection and exercising periods might be necessitated by the presence of deterioration or by hard starting or subnormal performance of the engine.

#### RESULTS OF COST ESTIMATIONS

The total acquisition, installation, and maintenance costs were estimated for each of the potential combinations of engine type, maintenance routine, fuel, and fuel storage facility. The results of these cost estimations for standby periods of 5, 10, and 15 years are presented in Table 9. More detailed tabulations showing the breakdown of costs for each system are given in Appendix A.

TABLE 7. SUGGESTED PROCEDURES FOR ACTIVE MAINTENANCE  
PROGRAM WITH INFREQUENT EXERCISING

Operation	Frequency	Labor Hours	Materials Used
<b>Maintenance</b>			
o change engine oil and coolant, replace oil filter and fuel filter (diesel engine) clean air cleaner, lubricate motor, generator and pump bearings, use preservative oil (MIL-L-21260) in engine lubrication system, use conventional lubricants, greases and coolant (with rust inhibitor added)	annually	2	lubricants, grease, coolant
o maintain starting battery on trickle charge	continuously	none	2kw-hr/day
o maintain low humidity in engine room with refrigeration-type dehumidifier	continuously	none	10 kw-hr/day
o replace or recondition worn or failed parts as needed and maintain proper lubricant, coolant, and battery electrolyte levels		--	--
<b>Exercising</b>			
o start engine and allow to warm up at fast idle	every 6 weeks	1/2	fuel
o run at 80 percent load or higher for 1/2 hour	every 6 weeks	1/2	fuel
o observe and record performance data	every 6 weeks	--	--
<b>Inspection</b>			
o inspect engine, generator, fuel system, exhaust system, starting system, and other critical components for leaks or other evidence of malfunction or deterioration	every 6 weeks	1	none
o perform detailed inspection including electrical system checks on generator and motors, specific gravity and voltage of batteries and mechanical condition of all components of installation	annually	2	none

TABLE 8. SUGGESTED PROCEDURES FOR  
PASSIVE MAINTENANCE PROGRAM

Operation	Frequency	Labor Hours	Materials Used
<b>Preservation</b>			
o fill crankcase with MIL-L-21260 preservative oil	annually	1/4	oil
o fill cooling system with MIL-C-16173 grade 3 corrosion preventive before engine preservation run, drain when preservation is completed	annually	1/4	preservative
o start engine and run on fast idle until warmed up using good grade of fresh fuel, run at 3/4 speed no load and switch fuel line to portable fuel tank containing VV-L-800 preservative oil, continue running until engine begins to misfire (if gasoline engine) or blue smoke appears in exhaust (if diesel engine), immediately shut engine off, LPG engine can be run out on standard commercial grade LPG fuel	annually	1/2	fuel
o allow engine to cool to under 100 F and then atomize MIL-L-21260 preservative oil into cylinders through spark plug openings (for gasoline or LPG engines) or through intake valves (for diesel engines) while cranking engine with starter, spray MIL-L-21260 preservative oil into valve chambers, blow MIL-P-22110 VCI crystals into cylinders and valve chambers and replace spark plugs and valve covers	annually	2	oil, VCI crystals
o clean air cleaner with MIL-L-21260 preservative oil	annually	1/2	oil
o spray MIL-C-16173 grade 1 corrosion preventive on all unpainted exterior surfaces	annually	1/2	preserv.
o spray ignition insulation compound on electrical wiring and components	annually	1/2	preserv.
o fill cooling system with water and O-I-490 corrosion inhibitor (5 oz. to 10 qts. water)	annually	1/2	preserv.

TABLE 8 (con't)

Operation	Frequency	Labor Hours	Materials Used
<b>Maintenance</b>			
o lubricate motor, generator and pump bearings	annually	1/2	grease
o maintain starting battery on trickle charge	continuously	none	2 kw-hr/day
o maintain 45 percent relative humidity in engine room with desiccant-type dehumidifier	continuously	none	5 kw-hr/day
o replace or recondition worn or failed parts and maintain proper lubricant, coolant, and battery electrolyte levels	as needed	--	--
<b>Exercising</b>			
o start engine and allow to warm up at fast idle	annually	1/2	fuel
o run at 80 percent load or higher for 1 hour	annually	1	fuel
o observe and record performance data	annually	--	--
<b>Inspection</b>			
o inspect engine, generator, fuel system, exhaust system, starting system and other critical components for leaks or other evidence of malfunction or deterioration	every 3 mos.	1	none
o perform detailed inspection including electrical system checks on generator and motors, specific gravity and voltage of batteries, and mechanical condition of all components of installation	annually	2	none

TABLE 9. TOTAL ESTIMATED COSTS FOR ACQUISITION, INSTALLATION AND STANDBY  
MAINTENANCE OF SELECTED FUEL SYSTEMS AND ENGINE EXERCISING ROUTINES

		TYPE OF STORAGE FACILITY											
FUEL TYPE	EXERCISING FREQUENCY	Vented Underground Tank			Sealed Underground Tank			Nitrogen Blanket					
		Standby Period, Years											
		5	10	15	5	10	15	5	10	15	5	10	15
Gasoline, Commercial Grade	Weekly	14,231	20,749	27,267	13,808	20,286	26,724	13,948	20,446	26,601			
	Every 6 Weeks	9,726	11,809	13,892	9,373	11,416	13,419	9,513	11,576	13,336			
	Yearly	9,821	11,414	13,007	9,478	11,031	12,544	9,618	11,191	12,461			
Gasoline, Special Blend	Weekly	13,865	19,960	26,015	13,865	19,920	25,975	14,005	20,160	26,317			
	Every 6 Weeks	9,350	11,010	12,670	9,430	11,050	12,670	9,570	11,290	13,010			
	Yearly	9,455	10,625	11,795	9,535	10,665	11,795	9,675	10,905	12,137			
Diesel, Commercial No. 2	Weekly	16,751	23,052	29,313	16,681	22,686	28,691	16,861	23,006	29,127			
	Every 6 Weeks	12,281	14,192	16,063	12,291	14,122	15,777	12,471	14,226	15,941			
	Yearly	12,366	13,787	14,952	12,396	13,737	14,902	12,576	13,957	15,082			
Diesel, Special Blend	Weekly	16,655	22,700	28,745	16,735	22,740	28,745	16,875	22,980	29,089			
	Every 6 Weeks	12,265	13,920	15,575	12,345	13,960	15,575	12,485	14,200	15,915			
	Yearly	12,370	13,535	14,700	12,450	13,575	14,700	12,590	13,815	15,066			
Kerosene	Weekly	15,734	22,784	29,068	16,704	22,714	28,724	16,884	22,894	28,999			
	Every 6 Weeks	12,259	13,914	15,803	12,309	13,924	15,539	12,489	14,104	15,117			
	Yearly	12,344	13,509	14,674	12,414	13,539	14,664	12,594	13,719	14,844			
LPG	Weekly	-	-	-	15,570	21,600	27,630	-	-	-			
	Every 6 Weeks	-	-	-	11,125	12,710	14,295	-	-	-			
	Yearly	-	-	-	11,225	12,315	13,405	-	-	-			

The sources and values used for all equipment, material, and installation costs are discussed in the previous two sections of the report, with the exceptions of the labor cost of inspection, servicing, and exercising, and the cost of the electrical power consumed by equipment operating in the shelter during the standby period. The inspection, servicing, and exercising duties could be either performed by an outside organization under contract or by individuals directly hired by OCD. In either case it is expected that the cost would be on the order of \$10 per hour. The cost of commercial electric power used during the standby period was estimated on the basis of 2-1/2 cents per kwh if the consumption is less than 250 kwh per month and 2 cents per kwh if the consumption is over 250 kwh per month.

A study of these results leads to a number of important general conclusions. First, exercising the engine every 6 weeks rather than every week results in a significant cost advantage. The passive maintenance routine calling for yearly exercising results in only a small saving over exercising every 6 weeks. Second, the use of a gasoline engine as the prime mover results in lower overall costs regardless of the fuel storage routine or engine exercising routine selected. Third, the differences in overall costs resulting from the three fuel storage facilities evaluated are relatively small. Fourth, the use of special blend fuels results in small cost savings in many but not all cases. Fifth, on the whole, overall costs are relatively insensitive to the fuel system costs. A number of graphs have been prepared from selected data to illustrate these conclusions.

Figure 7 shows the relationship between total cost and standby period for the three different engine maintenance routines evaluated in this study. Exercising every 6 weeks results in only about half the cost of exercising weekly for a standby period of 15 years. Exercising once a year results in only slight additional cost savings for standby periods from 7 to 15 years, due primarily to the higher initial cost for dehumidification equipment and preservation. These data represent a gasoline engine prime mover using commercial grade gasoline and a vented underground tank fuel storage facility.

Figure 8 shows a comparison of the three different engine types considered in this study. The higher initial cost of the LPG engine compared with the gasoline engine is due mainly to the high cost of its fuel storage facility. The costs of maintaining the LPG and diesel engine fuel systems are lower than for the gasoline engine fuel system, as evidenced by the reduced slope of the curves, hence, for standby periods of 20 years or more the cost advantage of the gasoline engine power system may be negligible. These data represent the use of commercial fuels in a vented underground tank (for the gasoline and diesel engines), and an exercising routine of every 6 weeks.

Figure 9 shows a comparison of the three different fuel storage facilities evaluated during this study. Both the sealed underground tank and the nitrogen blanket systems result in about the same cost for the 15 year standby period. However, the nitrogen blanket system is more expensive for shorter standby periods. The differences are not significant, however. These data represent a gasoline engine prime mover using commercial grade gasoline and an exercising routine of every 6 weeks.

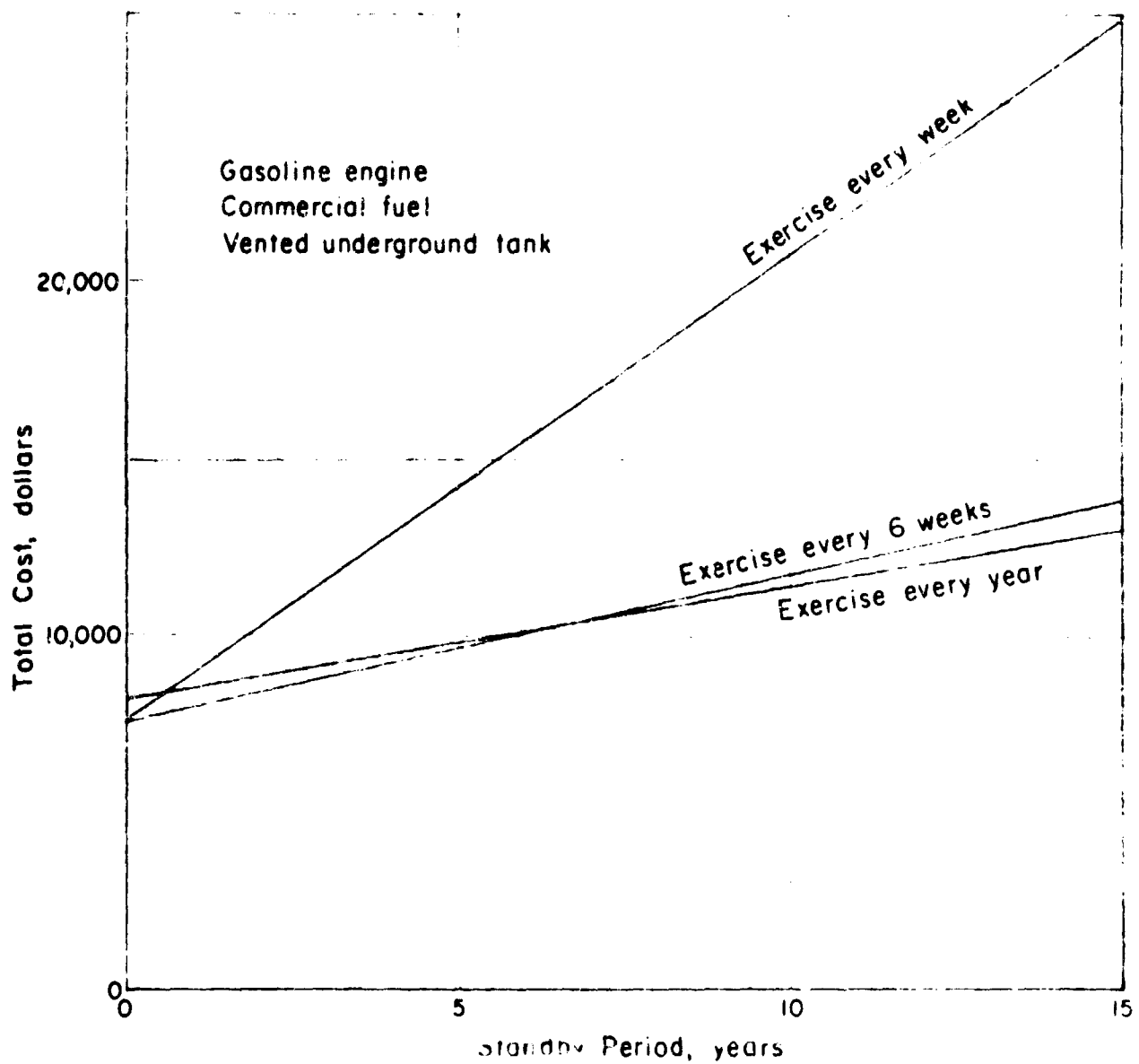


FIGURE 7. EFFECT OF EXERCISING ROUTINE ON TOTAL SYSTEM COST

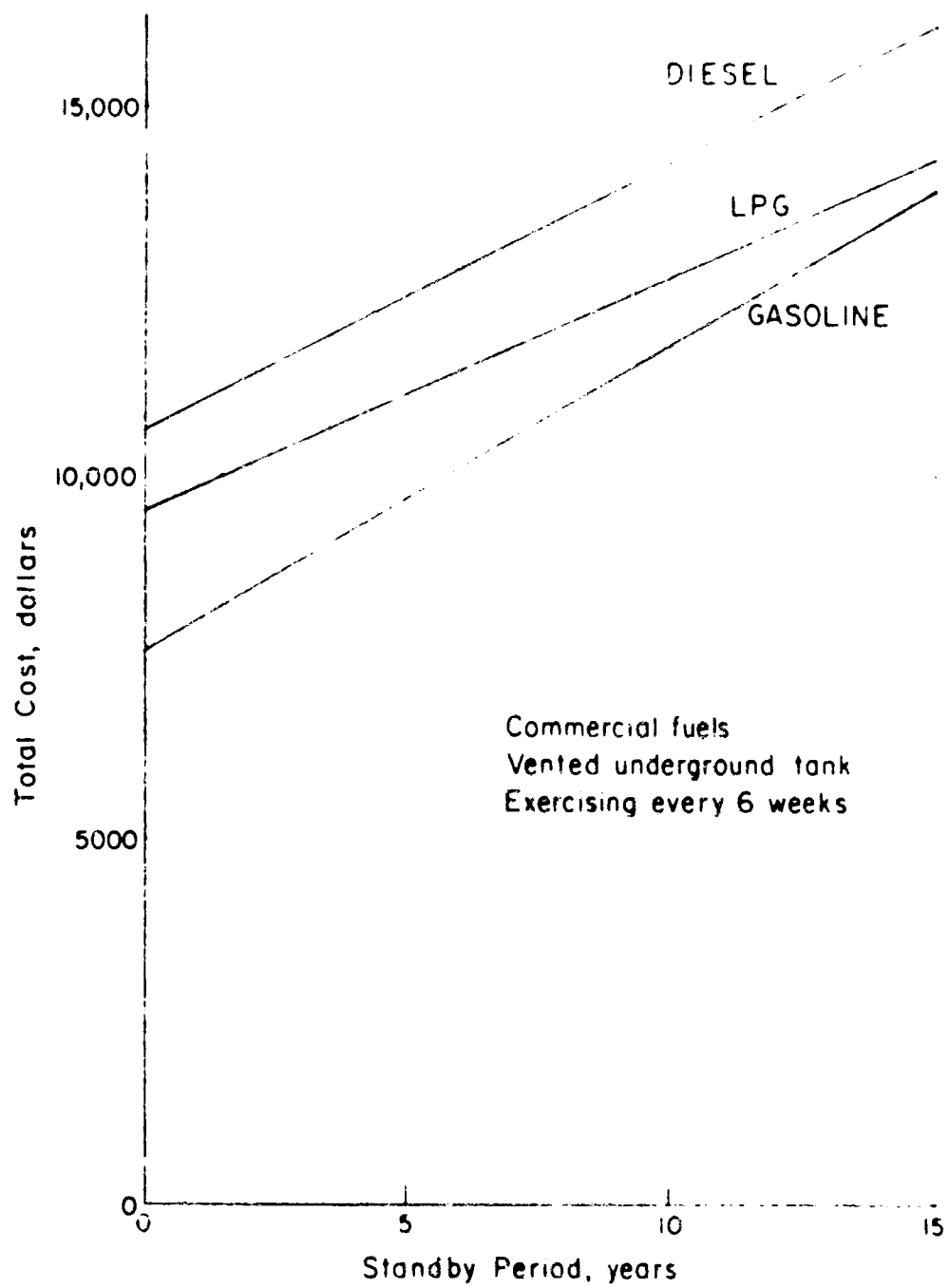


FIGURE 8. EFFECT OF ENGINE TYPE ON TOTAL SYSTEM COST



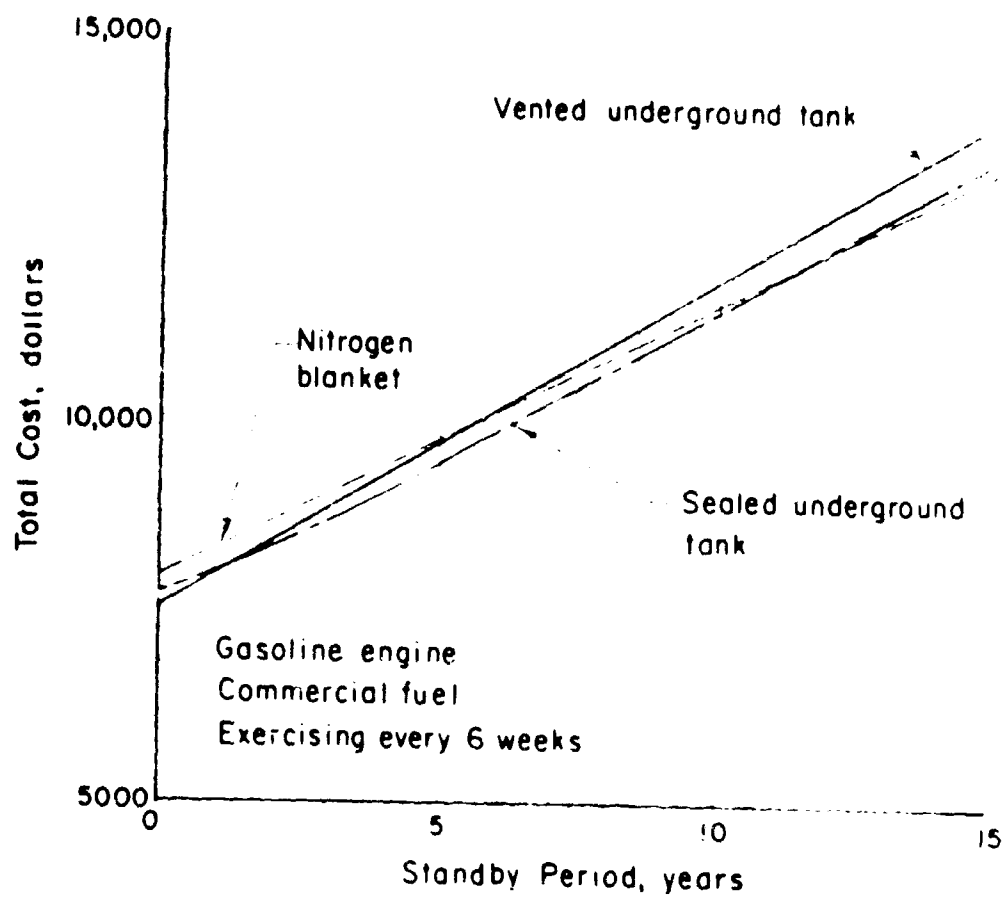


FIGURE 9. EFFECT OF FUEL STORAGE FACILITY ON TOTAL SYSTEM COST

Figure 10 shows a comparison of the use of commercial grade and special blend gasolines. The cost reduction from using special fuel appears to be substantial for the 15 year standby period. These data represent the use of a vented underground tank and an exercising routine of every 6 weeks.

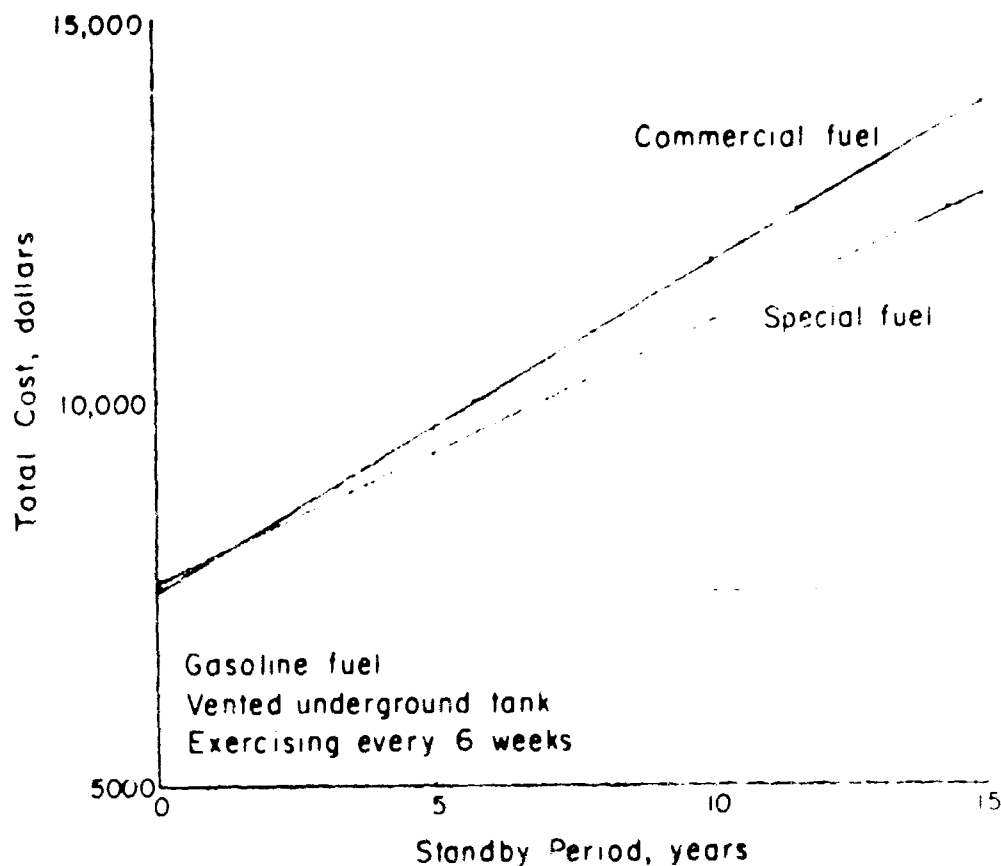


FIGURE 10. EFFECT OF FUEL TYPE ON TOTAL SYSTEM COST

Figure 11 shows a breakdown of the major individual costs for gasoline, LPG, and diesel engine auxiliary power systems based on a 15 year standby period. These data represent the use of commercial fuels, a vented underground tank (for the gasoline and diesel engines), and an exercising routine of every 6 weeks. It is easy to see from these data why the overall costs are relatively insensitive to the fuel system costs. The total fuel system cost, including fuel, tank and maintenance, is only about 13% of the total for the gasoline engine, about 21% for the LPG engine, and about 10% for the diesel engine. The fuel-only costs are on the order of 1 to 2-1/2 percent of the total.

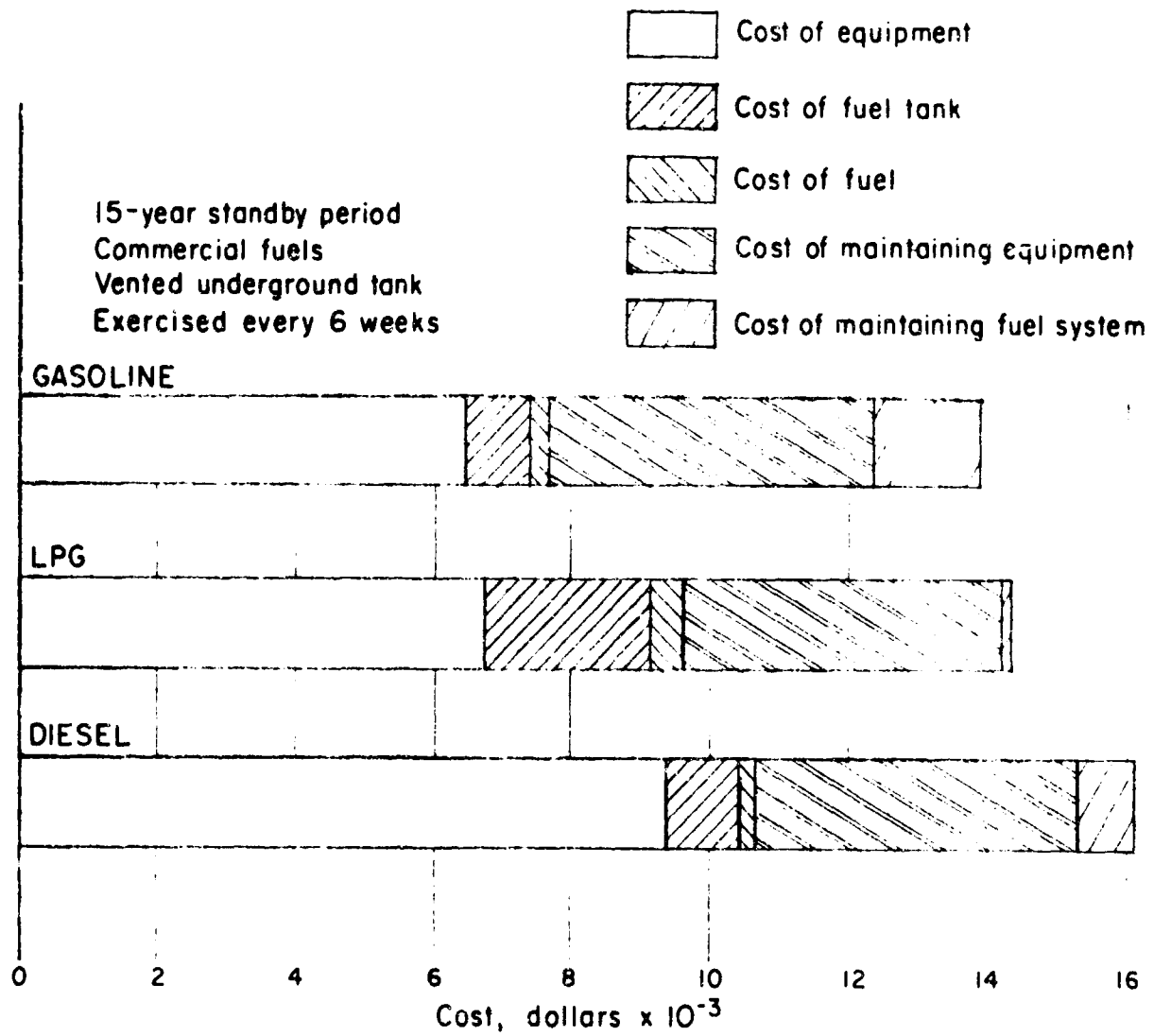


FIGURE 11. COMPARISON OF SHELTER POWER SYSTEM COST BREAKDOWNS  
FOR PRINCIPAL ENGINE TYPES

## FUTURE RESEARCH NEEDS

In the course of this research study a number of technological areas were noted in which presently available experience was inadequate to meet completely the needs of community shelters in respect to standby storage. Information is particularly sparse in the areas of long-term storage effects on commercial and special fuels, "dead" storage of engine-generator sets in a reasonable state of readiness, and the actual fuel-deterioration tolerance of gasoline and diesel engines. Battelle recommends that further research be conducted in these areas because of their importance to the community shelter program.

### In-Storage Evaluation of Selected Fuels

Aside from a few isolated cases, very little specific information was uncovered on the long-term aging characteristics of commercial fuels. It was also apparent from the current state-of-knowledge that accelerated aging techniques are not capable of predicting fuel life beyond a few years. It is evident that fuel deterioration-in-storage characteristics uniquely pertinent to the community shelter program can only be obtained by conducting an OCD-directed long-term aging program.

The recommended long-term aging program should comprise three simultaneous phases, as outlined below.

#### Phase A

Acquire existent-property data for odd samples of fuels, as they are located, which happen to have acquired 5 years or more aging time at various refineries and depots. This could be initiated by a country-wide solicitation of appropriate companies and government agencies. The basic stipulation should be that the fresh properties and aging conditions for each sample are well enough documented that the after-aging data will be meaningful. In general, the analyses had best be done by the sample owners themselves, under purchase orders issued by the contractor for the overall aging study. These data should go far toward confirming the indications of the quite-limited information now available about effects of long-term aging on fuels.

#### Phase B

Plan and initiate a long-term program for study of aging of selected commercial and "ideal" fuels under a series of storage conditions which involve various departures from an "ideal" condition. Specific features of the study might include:

Fuel Selection. Gasoline, diesel and gas-turbine fuels in both commercial grades and special blends according to a requirement for minimum existent sediment, gum, and non-hydrocarbon constituents, which could be met in large-volume production currently at a delivered cost of, say, no more than 20 to 25 cents per gallon.

Storage Conditions. The ambient temperature should be no higher than that of a cave floor ca. 10-feet underground. New, clean containers, probably 55-gal drums, made from mild steel, aluminum, and a glass-reinforced plastic material should be used with each type of fuel. Provisions should be made for each fuel/container combination to age the fuel with and without the presence of a "normal amount" of air, and of course to permit sampling of the fuels without significant perturbation thereof.

Analyses. It would appear that only a relatively simple set of periodic analyses would be necessary, e.g.:

- o Sediment
- o Existent gum
- o Hydroperoxides.

An alternate interesting possibility would involve primary determination of monochromatic light transmittance, possible at 350 millimicrons, or at several selected wave lengths. The other methods would be employed only to investigate more thoroughly any changes in a fuel detected by its light transmittance. Analyses at approximately 12-month intervals would probably be sufficient.

Certain accelerated aging tests (e.g., potential gum and potential sediment should also be run on the fresh fuels. The results would be useful for assurance about the fuels' initial quality. Otherwise, their comparison with the eventual aging data would provide a critical evaluation of the accelerated aging methods per se.

### Phase C

Conceive and evaluate various accelerated-aging tests, using the fuels in storage, and check the test results against actual deterioration.

### Experimental Study of Passive Standby Maintenance

Emergency engine-generator sets are normally maintained in a state of readiness by frequent exercising and inspection. The potential advantages of passive standby maintenance have been pointed out in previous sections of this report. The objectives of this suggested experimental study would be to demonstrate the feasibility of the passive maintenance technique and to develop specific procedures leading to maximum cost effectiveness.

At least 10 engine-generator sets of each type (i.e., gasoline, LPG, and diesel) should be acquired for this study. Although this number of units would not provide a statistical sampling, it would allow a certain amount of flexibility in the procedures and increase the confidence level in the results. These units should be in the 15 to 30 kw size range. Larger sizes would be more expensive and difficult to work with, and possibly less representative of the majority of shelter installations.

Each unit should be installed and preserved for standby storage according to the procedures and routine described in the "Prime Mover Maintenance" section of this report. The routine for passive standby maintenance described in Table 7 should be followed fairly closely, but variations could be introduced as might be indicated by further study of the shelter program needs. The units should be installed in one or more rooms in which the temperature and humidity conditions could be closely controlled to simulate an actual shelter environment. Ideally, each unit should be installed in its own controlled-environment space so that exercising and maintenance of one would not cause temperature and humidity condition changes that would affect the others. However, in the interest of economy and to simplify the facilities and procedures of the study, it would be acceptable to group up to 6 units in one simulated engine room, making the space large enough to minimize temperature and humidity changes when performing maintenance, inspection, and exercising.

The periodic exercising should be carried out as if the units were being reactivated in an emergency. For this purpose, the starting and operation of each unit should be planned so that personnel who would be expected to be on hand to perform these tasks in an actual emergency could do so successfully. After a period of 5 years or so it might be appropriate to put one or two units of each type through a full two-weeks operation at full load. Units designated for this test should each be in its own space so that the environmental conditions that might prevail in service could be simulated.

The full benefits from this experimental standby maintenance study would only be realized after a period of 10 years or more. However, significant information and experience would be gained from the beginning in determining the actual time and effort involved in the procedures, the level of experience needed, the reliability of starting an engine after a years' idleness, and the deterioration characteristics of the equipment under the preservation and storage conditions used.

#### Fuel-Deterioration Tolerance of Engines

Much work has been done to determine the gum and sludge formation characteristics of commercial fuels, and to measure or assess the tendency of various gasoline fuel blends to form induction system deposits. Standards for gum and sulfur content, corrosion properties, and vaporization characteristics for commercial fuels have been established with an apparent great emphasis on being conservative. The conservatism is, of course, justified when it is hoped that the engines using these fuels will operate up to 8,000 or 10,000 hours without a major overhaul.

On the other hand, for an engine that may be called upon to run for only 300 or 400 hours, the fuel may be deteriorated quite badly before it will have any appreciable effect on performance. The shelter application is a unique situation that calls for a reassessment of fuel quality standards.

A study should be conducted using artificially (or naturally, if available) deteriorated fuels to start and run an engine in a shelter power system

situation. The deteriorated fuel could be prepared by adding measured quantities of gum, sludge or other normally self-generated contaminants, by performing an ASTM accelerated aging test with an extended time period, or by introducing some material into the fuel that would act as a catalyst in the formation of contaminants. Determining the best method for aging of the fuel would be an important aspect of the study.

Engines vary widely in their tolerance to deteriorated fuels. For this reason it would be essential to evaluate the artificially deteriorated fuels in a number of different makes and models of engines so that the chances would be good for finding the poorest combination of fuel and engine to use as the basis for a minimum standard. The results of this study could be used not only as a guide in determining the extent to which a fuel may be allowed to deteriorate in storage but also as a factor influencing the type of standby maintenance technique to be selected for the fuel system.

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APPENDIX A

COMPLETE TABULATION OF SYSTEM  
COST ESTIMATION RESULTS

TABLE A-1

Engine Type	Gasoline																		LPG				
Maintenance Routine	Exercise every week						Exercise every 6 weeks						Exercise every year						Exercise every week	Exercise every 6 weeks	Exercise every year	Exercise every week	
Acquisition, \$	6,440						6,440						7,035						6,725	6,725	7,320	9,61	
Cost to Maintain, \$																							
5 Years	5,880						1,560						1,080						5,880	1,560	1,080	5,88	
10 Years	11,760						3,120						2,160						11,760	3,120	2,160	11,76	
15 Years	17,640						4,680						3,240						17,640	4,680	3,240	17,64	
Fuel Type	Commercial grade gasoline			Special blend gasoline			Commercial grade gasoline			Special blend gasoline			Commercial grade gasoline			Special blend gasoline			LPG	LPG	LPG	Kerosen	
Storage Facility																							
Type	VUT <sup>(1)</sup>	SUT <sup>(2)</sup>	NB <sup>(3)</sup>	VUT	SUT	NB	VUT	SUT	NB	VUT	SUT	NB	VUT	SUT	NB	VUT	SUT	NB	SUT	SUT	SUT	VUT	SUT
Cost, \$	930	930	1010	850	930	1010	860	930	1010	850	930	1010	850	930	1010	850	930	1010	2430	2430	2430	800	770
Emergency Fuel																							
Quantity, gal	2453	2453	2453	2453	2453	2453	2453	2453	2453	2453	2453	2453	2453	2453	2453	2453	2453	2453	2266	2266	2266	1804	1804
Cost, \$	343	343	343	440	440	440	343	343	343	440	440	440	343	343	343	440	440	440	385	385	385	234	234
Exercise Fuel																							
Quantity, gal/yr	190	190	190	190	190	190	32	32	32	32	32	32	11	11	11	11	11	11	175	29	10	140	140
Cost, \$/yr	27	27	27	27	27	27	4	4	4	4	4	4	2	2	2	2	2	2	30	5	2	18	18
Cost to Maintain, \$																							
5 Years	638	215	275	175	175	235	523	100	160	60	60	120	513	90	150	50	50	110	160	25	10	130	130
10 Years	1276	813	893	390	350	510	1046	583	663	160	120	280	1026	563	643	140	100	260	300	50	20	300	260
15 Years	1914	1371	1168	565	525	785	1569	1026	863	260	180	420	1539	996	833	210	150	410	450	75	30	440	390

(1) Vented underground tank.

(2) Sealed underground tank.

(3) Nitrogen blanketing.

A.

Diesel									Diesel																	
Exercise every week			Exercise every 6 weeks			Exercise every year			Exercise every week						Exercise every 6 weeks						Exercise every year					
9,610			9,690			10,285			9,610						9,690						10,285					
5,880			1,560			1,080			5,880						1,560						1,080					
11,760			3,120			2,160			11,760						3,120						2,160					
17,640			4,680			3,240			17,640						4,680						3,240					
Kerosene			Kerosene			Kerosene			Commercial grade No. 2 diesel			Special blend diesel			Commercial grade No. 2 diesel			Special blend diesel			Commercial grade No. 2 diesel			Special blend diesel		
VUT	SUT	NB	VUT	SUT	NB	VUT	SUT	NB	VUT	SUT	NB	VUT	SUT	NB	VUT	SUT	NB	VUT	SUT	NB	VUT	SUT	NB	VUT	SUT	NB
800	770	850	720	770	850	700	770	850	800	770	850	690	770	850	720	770	850	690	770	850	700	770	850	690	770	850
1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804	1804
234	234	234	234	234	234	234	234	234	216	216	216	270	270	270	216	216	216	270	270	270	216	216	216	270	270	270
140	140	140	23	23	23	8	8	8	140	140	140	140	140	140	23	23	23	23	23	23	8	8	8	8	8	8
18	18	18	3	3	3	1	1	1	17	17	17	17	17	17	3	3	3	3	3	3	1	1	1	1	1	1
130	130	230	55	55	155	45	45	145	165	125	225	125	125	185	95	55	155	55	55	115	65	45	145	45	45	105
300	267	367	157	110	210	130	90	180	586	250	490	290	250	410	446	326	350	150	110	270	426	306	146	130	90	250
704	390	497	473	165	265	215	135	235	967	375	731	455	375	635	757	421	505	245	165	425	511	391	491	215	135	395

B.

APPENDIX B

PRESERVATIVES-SPECIFICATIONS AND DESCRIPTIONS

## APPENDIX B

### PRESERVATIVES - SPECIFICATIONS AND DESCRIPTIONS

Following is a list of military specification preservative materials which have been deemed applicable to the preservation of shelter auxiliary power systems.

<u>Specification No.</u>	<u>Type</u>	<u>Title</u>
O-I-490		Corrosion inhibitor, cooling system
VV-L-800 (MIL-L-644)	P-9	Lubricating oil, general purpose, preservative, (water-displacing, low temperature)
MIL-B-131		Barrier material, water vaporproof, flexible
MIL-F-149		Plastic coating compound, strippable, (hot dipping)
MIL-D-3464		Desiccants, activated, bagged, packaging use and static dehumidification
MIL-I-8574		Inhibitors, corrosion, volatile, utilization of
MIL-G-10924	P-11	Grease, automotive and artillery
MIL-C-11796	P-6	Corrosion preventive, petroleum, hot application
MIL-C-16173	P-1,P-2,P-3	Corrosion preventive compound, solvent cutback, cold application
MIL-I-21260	P-10	Lubricating oil, internal-combustion engine preservative
MIL-B-22110		Inhibitors, corrosion, volatile, crystalline
MIL-I-23310		Inhibitors, corrosion, volatile, oil type
MIL-I-26860		Indicator, humidity, plug, color change
MIL-I-46002		Lubricating oil, contact and volatile corrosion inhibited

Following is a partial list of government publications relating to preservation techniques.

<u>Publication No.</u>	<u>Date</u>	<u>Title</u>
MIL-P-116E	Nov. 1, 1965	Methods of Preservation
MIL-E-10062 B	July 29, 1963	Preparation for Shipment and Storage of Engines
TM 38-450	April, 1965	Inspection, Care and Preservation of Prepositioned Material
AMCP 706-121	Oct., 1964	Packaging and Pack Engineering
NAVDOCKS TP-PW-14	July, 1957	Preservation, Packaging, and Packing of "C" Cognizance Material
MIL-C-45360 A (MO)	Oct. 1, 1963	Processing for Storage and Shipment of Armored, Full-Track Personnel Carriers

Following is a list of preservatives by type and general application.

<u>Type</u>	<u>Application</u>
P-1	Shafts and couplings
P-2	Lube systems, sleeve bearings and housings, ferrous slip rings and brush springs
P-3	Compressor cooling system flush
P-5	Flexible couplings
P-6	Flexible couplings, battery cable terminals
P-7	Ferrous slip rings and brush springs
P-9	Diesel fuel system
P-10	Compressor crankcase, air cleaner, compressor cylinder, lube systems, sleeve bearings and housings
P-12	Ferrous slip rings and brush springs
P-15	Hydraulic fluid supply tank

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13. ABSTRACT			
<p>The study described in this report covered two closely related areas of investigation: (1) the deterioration of fuels and equipment in storage and (2) the standby maintenance requirements of auxiliary power systems for community protective shelters. Determination of the state-of-knowledge and current practices in the first area of investigation led to the devising of specific plans of action in the second area.</p> <p>A number of plans for standby-maintenance routines for community shelter power systems were devised during the study. These plans are based on the best information available from the literature and from field experience. The costs for acquisition, installation, and maintenance of these systems and for the standby maintenance routines are estimated and compared on the basis of 5-, 10-, and 15-year standby periods. From the results it appears that a gasoline engine power system utilizing commercial fuels and preservatives, maintained in a low-humidity environment, and exercised every 6 weeks, would provide maximum cost effectiveness considering the present state of knowledge.</p> <p>It was noted during this study that information is particularly sparse in the areas of: long-term storage effects on commercial and special fuels and lubricants, inactive storage of engine-generator sets in a reasonable state of readiness, and the fuel-deterioration tolerance of gasoline and diesel engines. Recommended specific research programs to close each of these technological gaps are briefly described.</p>			

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